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EVALUATION OF THE MELT-ZIT HIGH-TEMPERATURE INCINERATOR. OPERATION TEST REPORT, AUGUST, 1968

Consumer Protection and Environmental Health
Service
Washington, D. C.

1969

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ADDENDUM

to the Evaluation of the Melt-Zit High Temperature Incinerator Operation Test Report

April 1970

There have been several developments of interest with regard to the Melt-Zit process since the tests conducted in March 1968. In April 1969, Process Plants Corporation acquired American Design and Development Corporation and formed a new company, American Thermogen Incorporated, as a wholly owned subsidiary. Inquiries regarding the Melt-Zit incinerator should be directed to American Thermogen Incorporated, 200 Essex Street, Whitman, Massachusetts 02382.

Since March 1968, several improvements and modifications have been made in the design of the facility at Whitman; these have included:

Installation of an automatic fuel weigh conveyor;

Installation of an automatic batch-cycle residue and fly ash weigh conveyor;

Addition of a manual, pneumatically controlled forced air damper;

Modified charging door and charging chute to prevent mechanical bridging;

Ia

Expansion of primary combustion zone of furnace;

Shortening of slag taps;

Installation of a steam injection system* for air pollution control to replace the wet venturi which had not been tested in March 1968;

Installation of a process water cooling system as part of the steam injection system;

Increased process instrumentation.

Experience has also led to improvements in operating techniques, including standardized ignition and warmup procedures, uniform charging methods, maintenance of optimum coke bed level, and incorporation of flushing techniques to control the melt rate.

A followup demonstration was held at Whitman on September 3, 1969. Officials from the Lower Passaic Valley Solid Waste Management Authority and representatives of the Bureau of Solid Waste Management were present. The objective was to operate the facility continuously in order to demonstrate the effectiveness of the modifications and new operating techniques. No detailed performance data were sought.

The unit operated without any apparent difficulty during the scheduled 14-hour run. Process instrumentation indicated no unusual fluctuations in operating parameters. From all indications, the process operated quite satisfactorily.

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*The steam jets also substitute for the I. D. Fan used in the earlier wet venturi to control pressures throughout the system.

Encouraged by the apparent workability of the Melt-Zit, the Lower Passaic Valley Solid Waste Management Authority representatives decided that the system could be considered for large-scale application. Their pursuit of the matter with American Thermogen and the Bureau has resulted in a demonstration grant being awarded the Authority to demonstrate and evaluate a full-size plant having a capacity of 1,000 tons per day. The two-year project began March 1, 1970.

American Thermogen will design, build, own, and operate the plant through a long-term contract with the Authority. The facility will be constructed on land owned by the Authority and will serve the cities of Clifton, Paterson, Wayne, and Passaic, New Jersey.

The Bureau will support the Authority during the preparation of the contract and for one year of operation after an acceptable one is negotiated. The contract will establish particulars as to cost, rate of usage, compliance with state and local pollution codes, and access to data for purposes of demonstration and evaluation. The one-year operation will allow sufficient time to thoroughly evaluate the process and its economic practicability and the performance characteristics of the incinerator and associated systems.

IN

EVALUATION OF THE MELT-ZIT HIGH-TEMPERATURE INCINERATOR

Operation Test Report

August 1968

This report was prepared for the
City of Brockton under Grant No. DO1-UI-00076
by Elmer R. Kaiser, Consulting Engineer

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
Environmental Control Administration
Bureau of Solid Waste Management
Cincinnati
1969

Id

2d printing
1970

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II

PREFACE

An estimated 900 million pounds of wastes in the solid state are produced in the United States every day. What to do with these solid wastes, how to dispose of them without needlessly endangering public health and welfare, and how to recover and reuse valuable materials now "thrown away" are among the most challenging and perplexing of current national problems. Because of lack of suitable planning, interest, and public understanding, these problems have reached such proportions that nationwide attention is demanded and action for the development of adequate solutions must be taken.

Intensified action concerning these problems was made possible by the Solid Waste Disposal Act, Title II of Public Law 89-272, which was signed by the President on October 20, 1965. This legislation directs the Secretary of the Department of Health, Education, and Welfare to initiate, encourage, and support a national program aimed at discovering and evaluating better methods of coping with the solid waste problem.

The Secretary is authorized (1) to conduct and support research on the nature and scope of the problem, on methods of more safely and efficiently collecting and disposing of solid wastes, and on techniques for recovering from solid wastes potentially valuable materials and energy; (2) to provide training and financial and technical assistance to local and State agencies and other organizations in the planning, development, and conduct of solid waste management programs; (3) to encourage and support projects that may demonstrate new and improved methods of solid waste collection, handling, and disposal. The Bureau of Solid Waste Management carries out these responsibilities.

Among these responsibilities, the Bureau provides grant support for demonstrations relating to the development and application of new and improved methods of solid waste collection, storage, processing, and ultimate disposal; and grants for studies and investigations that may lead to a demonstration of improved disposal practices, or may provide solutions for regional or national solid waste disposal problems. Associated with this is the responsibility for collecting and making available by appropriate means the results of, and other information pertaining to, such federally supported demonstrations, studies, and investigations.

Accordingly this report has been reproduced to disseminate as widely as possible the latest available information and findings of a project that has received grant support from the Bureau of Solid Waste Management. It is felt that this report will be of considerable interest since it provides some of the first information available on high-temperature incineration, at a time when widespread interest in this process is evident.

This is an interim report of project progress. Additional work is currently underway to complete the project. The final report will be issued as a Public Health Service publication.

--RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

ABSTRACT OF STUDY AND INVESTIGATION GRANT NO. D01-UI-00076

TITLE: Evaluation of the Melt-Zit high-temperature incinerator

GRANTEE: City of Brockton

PROJECT DIRECTOR: John E. Sullivan, Mayor
City of Brockton
City Hall
Brockton, Massachusetts 02401

PROJECT STARTED: November 1, 1967

PROJECT ENDS: March 31, 1968

OBJECTIVES: To demonstrate a new method of solid waste incineration, and to evaluate its performance in terms of its potential for practical application.

PROCEDURES: An existing Melt-Zit high-temperature incinerator located at Whitman, Massachusetts, will be tested and evaluated. Prior to the tests, the facility will be instrumented, equipped with platform and second stack port, and provided with separate water circuits for slag quenching and gas scrubbing. The incinerator will be operated for 2 days to train the test crew and establish the full-load rating that could be reliably sustained.

The main test is to be a continuous run of 4 days, using a mixture of refuse and garbage supplied by the City of Brockton. The incinerator will be charged for the first 2 days at its rated full load, then for 24 hours at three-fourths of rated full load, and then for 24 hours at one-half of rated full load. The fifth day's testing will consist of 8 hours of start-and-stop operation to evaluate the unit under those conditions.

Operation tests will be performed by Elmer R. Kaiser Consulting Engineer, Scarsdale, New York, who will also prepare the final report of the study. Wisconsin Chemical and Testing Company of Milwaukee, Wisconsin, will conduct air pollution emission studies. The consulting engineering firm of Fay, Spofford, and Thorndike, Inc., Boston, Massachusetts, will provide general engineering services associated with the testing. The American Design and Development Corporation, Whitman, Massachusetts, will furnish the pilot plant and support related thereto for the tests.

November 1, 1968

FOREWORD

High temperature incineration as utilized in the Melt-Zit Process includes the use of a vertical shaft furnace operating between 2600° and 3200°F. Thus, combustibles are incinerated and non-combustibles are converted to a molten residue which flows as a liquid stream from the base of the unit. When cooled or quenched rapidly in water this residue takes the form of frit or sand-like particles, black in color, sterile and inert.

Recognizing the possibilities of high temperature incineration, American Design & Development Corporation constructed a test facility in the town of Whitman, Massachusetts. This experimental unit,for the past two years, has been operated as a development facility to provide data for commerical designs and operating techniques. It was not intended as a commercial unit. It has frequently been displayed in operation to interested public officials and others in an effort to introduce the high temperature incineration concept and the eventual marketing of the process.

The City of Brockton, Massachusetts, (pop. 90, 000) had just completed a broad study of methods of refuse disposal and was impressed with the possibilities of high temperature incineration. The City sponsored a demonstration grant project, No. 1-DO1-U1-00076-01, Department of Health, Education and Welfare, Environmental Control Administration, Solid Wastes Program, on a one-third City and two-thirds Federal basis, under which a total of $67, 700 was made available for testing the high

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temperature burning facility.

The results of the tests, which were conducted from March 14 to 23, 1968, are described in detail in the accompanying report. Test results of particular interest to public officials considering incineration are evaluated in this foreword.

It is suggested that public officials and others interested in incineration and the results of these tests, should refer this report to their consulting engineer for evaluation and advice in relation to their particular needs.

Inquiries as to future plans for the Melt-Zit Process should be directed to American Design & Development Corporation, 200 Essex Street, Whitman, Massachusetts 02382.

The Melt-Zit Facility.

The Melt-Zit principle is unique in the art of incineration. The non-combustible fractions of the refuse are melted in a bed of high temperature coke, and drained from the furnace as molten slag and iron. Organic matter in the residue is thereby automatically prevented and complete sterility is achieved. The residue has a high density.

The Melt-Zit pilot installation is basically a vertical, cylindrical shaft furnace with refractory lining. The inside diameter is 3 feet (minimum) and the height 55 feet.

The molten residue, a slag-like material, including metal, is drained through an opening at the base, above the hearth; it drops into a quenching tank of water where rapid cooling results in a black granulate and iron pellets.

Refuse is charged midway up the stack through an open charging chute. The refuse feed is continuous. The combustible materials burn in suspension while the heavier non-combustibles burn and melt on the surface of the fuel bed.

Performance of Melt-Zit Incinerator.

Based on the best period of the tests, the capacity of refuse input for the 3-foot diameter furnace was 1.6 tons per hour. The refuse was municipal rubbish and garbage, 90 per cent of the former and 10 per cent of the latter, by weight.

The operating temperatures in the coke bed were from 2600° to 3200°F.

The weight of slag (including metal) produced during the longest test run was 460 pounds per ton of refuse, or 23 per cent of the weight and 4 per cent of the volume of the refuse.

The pilot furnace was operated with direct discharge to the atmosphere at the top. The stack gas scrubber with which the furnace was equipped was not used, as it would have prevented proper sampling of the gases.

The maximum length of uninterrupted run during the tests was 62 hours. Interruptions were caused by mechanical failures in the slag removing conveyor system and trouble with the flow of slag due to its high viscosity.

Evaluation of Melt-Zit Incinerator.

In the state of development and method of operation of the Melt-Zit unit during the March 1968 tests, the pilot incinerator did not perform satisfactorily or reliably. The Melt-Zit incinerator, therefore, needs further development prior to full scale production. It is believed that the process has sufficient promise to warrant further design and development.

When improved performance can be demonstrated, the rated tonnages can be increased, probably up to 25 per cent.

A full scale incinerator of this type will require a secondary combustion chamber to further burn the gases and the particulate matter. The gases could then be cleaned of dust by conventional dust collectors.

It is estimated that the largest practicable size furnace is approximately 8 feet diameter with 15 tons per hour burning capacity.

The technical advantages of the Melt-Zit Process are a residue free of putrescible matter, maximum density in landfill, and the elimination of ground water or stream pollution from deposit of incinerator residue.

The most favorable rate of coke consumption during the test period was one ton of coke to 8 tons of refuse. It is believed, however, that by application of suggested improvements a ratio of 1 to 20 could be achieved.

Comparative construction and operating costs for a full scale Melt-Zit plant versus a conventional plant cannot be reliably anticipated from the test experience.

Melt-Zit costs include coke and limestone which are not common to other incinerators. These additional costs may be offset, however, by additional benefits such as less area required for landfill and reduced costs of residue disposal.

Participants in Tests.

The City of Brockton was sponsor, the project having been initiated during the term of Mayor Alvin Jack Sims and finalized under Mayor John E. Sullivan.

The Principal Investigator was Mr. Elmer R. Kaiser of New York University.

Air pollution emission tests were made by Mr. Fred R. Rehm, of Wisconsin Chemical and Testing Company.

Use of the test facility and its operation were furnished by American Design & Development Corporation.

General Consultant on behalf of the City of Brockton was the engineering firm of Fay, Spofford & Thorndike, Inc.

Present during the tests in an advisory capacity for American Design & Development Corporation were representatives of Turner Construction Company and Jones & Laughlin Steel Corporation.

FAY, SPOFFORD & THORNDIKE, INC.
Boston, Massachusetts

March 6, 1969

AMERICAN DESIGN & DEVELOPMENT CORPORATION'S COMMENTS CONCERNING THE CONSULTANTS TEST REPORT

Page 11 - Conclusion 1-G:

The writer of the Test Report is expressing a conclusion which we do not believe can be supported by the data and observations obtained during the test. He concludes the upper "refractory had not deteriorated because" solely due to temperature range experienced. We think that conclusion implies, first, that the refractory would deteriorate due to temperature alone and, of course, this would not necessarily be true(1) - obviously the quality of material as well as temperature and, perhaps, even erosion would be factors. This form of conclusion also begs the question - what temperatures should be experienced at this elevation?(2) In fact, the conclusion as stated involves consideration of a number of factors which cannot be accurately described purely from the test data. This sort of conclusion, we believe, could only be validly expressed after further study, tests and observations over an appreciable period of time under normal operating conditions.(3)

Continued test of the Destructor (furnace) operation, including several runs in excess of 24 hours with sustained temperatures above 2000°F. - since the March tests - have not resulted in observable or measurable loss of refractory in this area. We also think the reference to the upper refractory should be stated separately from consideration of the melt zone refractory. The conditions in the two areas are obviously quite different with different factors influencing refractory life.

We strongly urge restatement of the last sentence (1-G) and would suggest the following sentence be substituted as a more accurate and valid expression: "The refractory in the upper part of the furnace had not deteriorated."

Economic Evaluation Appendix B:

Our second area of concern rests with the inclusion in this Report, in its present form, of the economic evaluation as Appendix B. We appreciate the fact that the content is merely an expression of the writer's opinion. Unfortunately, and perhaps quite naturally, we do not share the writer's opinion relative to this subject. Some allowances should be made for rebuttal, at least to the extent the reader may be exposed to all facets of thinking in this area.

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Economic Evaluation Appendix B: (continued)

We agree with Mr. Kaiser that to undertake prediction of economics, the technical difficulty must be laid to rest on the assumption of solution.

Commencing then to state a view on the economics we believe the Melt-Zit facility is a system providing a solution to the total solid waste production of a community. Therefore, a comparison with other solutions - in particular conventional incineration - should include a view of total waste management based on the application of the two systems under study.

We think it is generally recognized that the application of present conventional incineration requires selectivity in the handling of refuse - a factor influencing costs. This selective handling must occur: (1) during collection, (2) at the incinerator, and/or, (3) rehaul of increased volumes of residue. Selective waste handling is the result of the inability of conventional incineration, as presently practiced, to consume or alter non-combustible waste products. This then leads to the requirement for dual waste disposal sites - (1) The facility, and (2) landfill - both of which must be staffed and maintained, with their concurrent increased waste traffic management.

Melt-Zit, on the other hand, favors one solution at one site. Segregation of garbage, non-combustible and combustible refuse is eliminated in collection and/or at the facility. Only the geometry of the feed product (waste) need be considered, and this is true of the application of any system - Melt-Zit or not. Rehaul is greatly simplified by the system (Melt-Zit) under consideration in this Report. Contrast the nature and reduction of refuse to an inert, sterile frit with the quality and quantity of residue produced at existing conventional facilities. Ease of handling, elimination of deleterious factors accelerating depreciation of equipment, and greatly reduced volumes of a nuisance-free residue are marked benefits for Melt-Zit. Attraction of rodents and contamination of water tables resulting from conventional residue all pose additional problems and costs. All the aforementioned factors we believe to be tantamount to any economic study as proposed in Appendix B. (We have not mentioned the possibility of reuse of Melt-Zit residue - studies are being made, see also pages B3 - B4 of the Test Report.)

Economic Evaluation Appendix B: (continued)

Having taken a broad view of the two methods, we next consider the impact on the capital costs and the operating costs of the respective installations. Basically the two facilities do and will contain the following components: receiving and transfer area; charging means; disposal equipment (furnaces); residue handling; and exhaust gas treatment and discharge. An analysis of conventional facilities reflects a rather large envelope housing both furnaces and receiving and storage areas. The receiving, storing and transfer has traditionally been by initial charge to large pits and transfer via overhead crane(s) to charging hoppers. The pits, sometimes exceeding dimensions of 100 x 40 x 30 feet (a capacity of nearly 4500 cubic yards or in excess of 1,000 tons), are extremely expensive, rarely completely cleaned and presently a challenge to fire protection. Trucks have been known to topple into these pits. The overhead crane is expensive as to initial investment, and certainly an expensive piece of equipment to maintain. In operation, it requires operators of experience who in themselves command a greater than average salary. Operators failing to report could cripple the facility. The charging system is usually an elevated hopper from which a traveling (or series of traveling) grates convey refuse to and through the furnace. Obviously this mechanism is entirely enclosed resulting in prohibitive on-stream repairs.

The furnaces, we believe, contain two significant drawbacks: (1) refractory configuration and, (2) moving parts - grates. It is for the most part a totally enclosed area - extremely susceptable to explosion (a frequent occurrence). Suspended ceilings, arches and the like contribute to high initial cost and difficult and costly maintenance problems. The traveling grates pose problems resulting from obstruction to movement, burn-out, and plugging of air-ports due to slagging. Distribution and agitation of refuse and the proper introduction of air pose obstacles to good combustion. Obviously, temperatures which melt non-combustibles or, in fact, meltable material is to be avoided (selectivity). Explosions and variable "hot spots" create further maintenance and control problems.

The matter of residue, as generally practiced, contributes significantly to the initial cost as well as recurring maintenance. This system usually involves transportation through water baths - where one may observe burned, partially burned and even unburned combustibles and organics. The result of which is a highly polluted, acid (usually warm) residue, which accurately stated is neither ash nor trash. Waste water and water supply pose problems and costs, not to mention ordinary housekeeping. Treatment of exhaust gases has been, to date, almost non-existant, thus, any comparison to "average" conventional facilities would be unfair. Most facilities claiming air pollution control as of date employ simple water sprays in baffle chambers, the result of which is obvious by inspection. Only recently has any attention been focused upon atmospheric contamination from incineration. Up to date facilities now under construction - employing the most recent technology - appear to equate to something in the order of slightly less than $10,000 per ton of rated capacity.

On the other hand, Melt-Zit facilities, as we view them, are fully capable of employing simple conveying systems feeding refuse continuously and result in less initial cost and cheaper operating expenses. Failure of a crane operator to report would have no effect. Automatic, variable-speed conveyor systems would be employed. An item easily repaired without serious interruption to operation - also completely exposed to facilitate rapid maintenance. Controlled charging would be effected by monitoring a graphic control panel displaying pressures and temperatures (which may be automated). Elimination of internal moving apparatus reduces initial investment and continuous mainenance costs. Simple cylindrical furnace configuration utilizing pre-cured, pre-cast refractory and repair rings, thus eliminating suspended ceilings and difficult archwork - results in reduction in first cost as well as maintenance. Design-wise the furnace has superior strength and, presenting essentially an open relief valve reduces significantly the hazard from explosion. Controlled temperatures insuring continuous flow of meltables which quench to frit reducing residue handling to a minimum-practically personnel-free. The end product is not only superior to conventional residue, but results in considerable less volume and, of course, is nuisance-free.

Air pollution control has been of prime consideration in the development of this system. Controlled velocities coupled with sufficient residence time present a minimum challenge to control of emission contamination. Even the solids recovered from the control system can be reintroduced for consumption and reduction to the harmless residue.

Thus, in our view, whether considered in the overall picture of municipal waste management, or in a detailed breakdown comparison, Melt-Zit seems to be, at best, extremely economical, but in any event certainly very competitive with conventional facilities.

-- A. DEAN TOMLINSON, Vice President

American Design & Development Corporation

NOTES: (1) Draft Report, page 63: "Refractories can operate indefinitely at these and higher temperatures when the latter are reasonably steady, . . ."

(2) Draft Report, page 63: "However, temperatures of 1800-2000°F. could be expected when the overall exhaust air rate is brough under control at 100 to 150 percent of stoichiometric for the total fuel and refuse charging."

(3) Draft Report, page 63: "The service life of refractory above the coke bed can only be determined over periods of a year or longer."

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TEST OF MELT-ZIT INCINERATOR

By Elmer R. Keiser, P.E.

Scarsdale, New York

Aug. 20, 1968

Incineration is the basic method for the reduction of municipal refuse to a minimum volume for disposal in landfilling. The increased generation of per capita refuse, and the decreasing land area for burial of wastes, favor the process. New principles and devices are being developed to improve the incinerator art so as to reduce the emissions of dust, odor, smoke and water contaminants, and to obtain a sterile residue of minimum volume. These results must be obtained in an economical manner.

The Melt-Zit principle is unique in the incinerator art. The noncombustible fractions of the refuse are melted in a bed of high-temperature coke, and drained from the furnace as molten slag and iron. Organic matter in the residue is thereby automatically prevented and complete sterility is achieved. The residue has a high density. The report discusses the testing and economics of this system.

A pilot-scale furnace for development and demonstration purposes is located at the American Design and Development Corp., 200 Essex Street, Whitman, Mass.

The incinerator test which is the subject of this report was sponsored jointly by the Department of Health, Education and Welfare, Environmental Control Administration, Solid Wastes Program and the City of Brockton, Mass. The test was conducted from March 14 to 23, 1968.

DESCRIPTION OF MELT-ZIT DESTRUCTOR AND OPERATION

The Melt-Zit pilot-scale incinerator is a complete system for refuse reduction, including the following major components:

a. Refuse receiving room

b. Refuse conveyor from receiving room to furnace

c. Coke feeder, coke and limestone elevator to furnace

d. Vertical shaft furnace

e. Venturi flue-gas scrubber with refractory-lined supply duct (secondary combustion chamber), quench section, flooded elbow, settling tank and sediment conveyor

f. Induced draft fan and flow damper

g. Residue quench tank, residue conveyor, quench water cooler

h. Forced air blowers

i. Control station

j. Building and utilities

Figure 1A is a sketch of the equipment that was part of the installation but was not included in the test.

Because the test was planned to exclude the performance of the gas scrubber, the system was modified to discharge the furnace exhaust gases directly to the atmosphere without the use of the hot-gas flue and gas scrubber. This change was necessary for the planned sampling of the gases for solids. Hence, the test was concerned primarily with the performance of the refractory-lined shaft furnace. The possible benefits of the additional combustion space, flow control, and air pollution control were thus not available to the test.

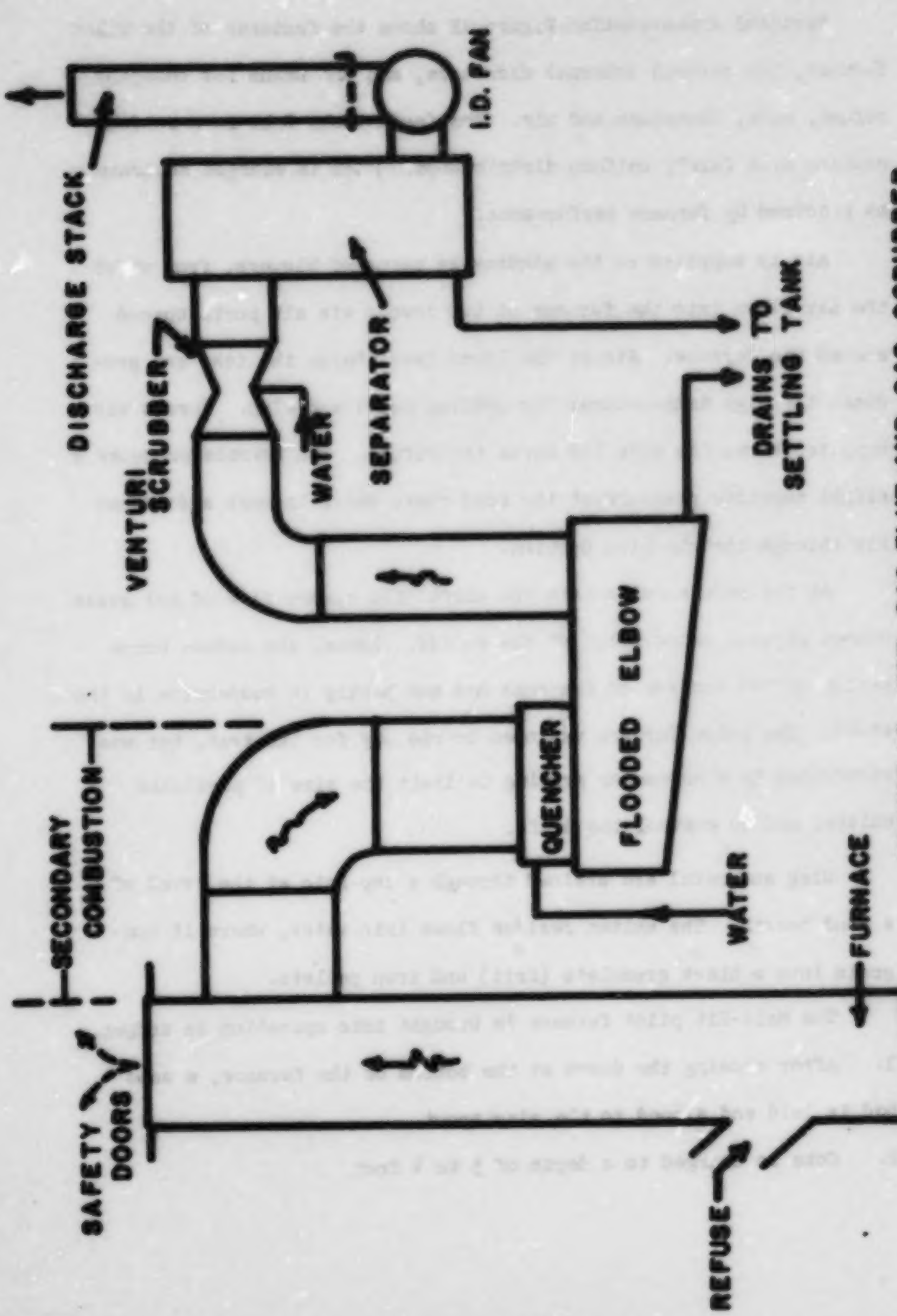
SAFETY DOORS
SECONDARY COMBUSTION
REFUSE
FURNACE
WATER
QUENCHER
FLOODED ELBOW
VENTURI SCRUBBER
WATER
SEPARATOR
DISCHARGE STACK
I.D. FAN
DRAINS TO SETTLING TANK

FIGURE 1A. HOT-GAS FLUE AND GAS SCRUBBER
(NOT TESTED)

Vertical cross-section Figure 1B shows the features of the pilot furnace, its several internal diameters, and the means for charging refuse, coke, limestone and air. The feed stocks fall in a random pattern with fairly uniform distribution. Each is charged separately as required by furnace performance.

Air is supplied to the windbox by means of blowers, from which the air flows into the furnace at two levels via air ports spaced around the furnace. Air at the lower level burns the coke and produces the high temperatures for melting metal and slag. Forced air supplied above the coke bed burns the refuse. The furnace produces a slight negative pressure at the feed chute which induces additional air through the charging opening.

As the refuse falls into the shaft, the upward flow of hot gases causes partial entrainment of the solids. Hence, the refuse burns partly on the surface of the coke bed and partly in suspension in the shaft. The pilot furnace was open to the sky for the test, but was surmounted by a screen or grating to limit the size of particles emitted and to control the draft.

Slag and metal are drained through a tap hole at the level of a sand hearth. The molten residue flows into water, where it congeals into a black granulate (frit) and iron pellets.

The Melt-Zit pilot furnace is brought into operation in stages.

1. After closing the doors at the bottom of the furnace, a sand bed is laid and sloped to the slag spout.
2. Coke is charged to a depth of 3 to 4 feet.

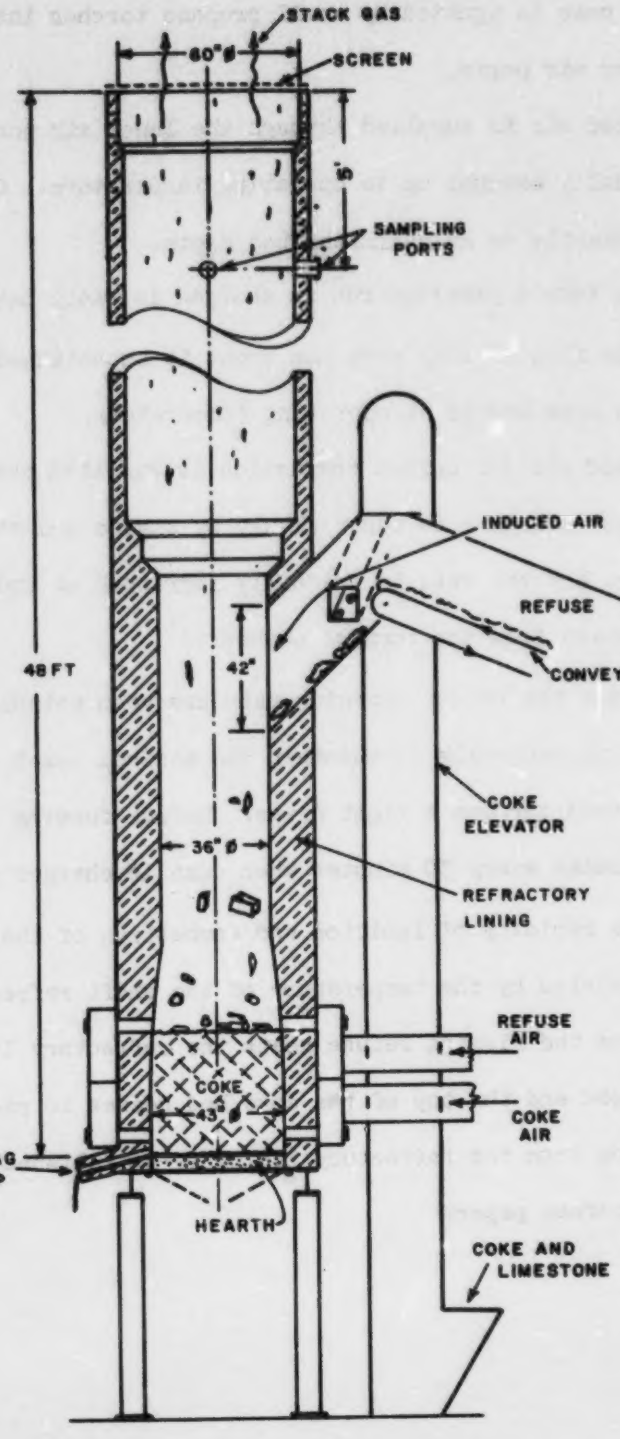
STACK GAS
60" ø
SCREEN
10'
SAMPLING PORTS
48 FT
INDUCED AIR
REFUSE
CONVEYOR
42"
COKE ELEVATOR
36" ø
REFRACTORY LINING
REFUSE AIR
COKE
43" ø
COKE AIR
SLAG TAP
HEARTH
COKE AND LIMESTONE

FIGURE 1B MELT-ZIT INCINERATOR

3. The coke is ignited by small propane torches inserted through the lower air ports.
4. Forced air is supplied through the lower air ports and the coke is gradually brought up to operating temperature. Coke is replenished intermittently to maintain the bed depth.
5. Slag from a previous run is charged in small batches until the flow of slag from the spout is established, as indication that the coke bed is at operating temperature.
6. Forced air for refuse combustion is supplied over the coke bed.
7. Refuse charging is begun slowly by starts and stops of the refuse conveyor, and the rate is gradually increased as indicated to be feasible by radiation from the furnace chamber.

After the refuse charging rate has been established, coke is charged periodically to maintain the desired level of the coke bed, as observed through a sight glass. Refuse feeding is halted for five minutes every 30 minutes when coke is charged and heated.

The rapidity of ignition and combustion of the refuse are mutually assisted by the temperature of the shaft refractory. The radiation from the flaming refuse heats the refractory lining. After coke is charged and the top of the coke bed ceases to radiate much heat, radiation from the refractory lining re-establishes prompt ignition of the refuse paper.

At no time is the refuse layer on the coke allowed to increase to more than a few inches, so as not to unduly divert the flow of gases from the coke bed.

At the end of a run the bottom of the furnace is opened and the remaining coke, slag and molten metal are dropped into a steel buggy

OBJECTIVES AND PLAN OF TEST

Objectives

The test was conducted to determine the degree to which the Melt-Zit principle had been developed for the reduction of municipal refuse. Specific items of interest were:

1. Capacity in tons per hour of refuse input per unit size of furnace, based on regular municipal refuse.
2. Ability to operate continuously over a period of days.
3. Consumption of coke, limestone, flux, power, water and auxiliary fuel if any.
4. Refractory wear and life expectancy.
5. Physical and chemical analysis of the slag.
6. Physical and chemical analyses of the refuse.
7. Emissions of gases and particulate matter from the stack.
8. Evaluation of the Melt-Zit unit as a municipal incinerator.

Plan

Two days of 24-hour operation were to be undertaken in succession to train the test crew and to establish the full-load rating that could be sustained reliably, but not to exceed 4 tons per hour of refuse containing 10 to 15 per cent by weight of garbage. Experience was to be gained with the size of paper particles that reach the particulate sampling probe. The full-load rating established from the two-day run was to be the basis for the charging rates during the following week.

The main test was to be a continuous run of four days (96 hours). The first 48 hours were to be at full rate of refuse charging. As received from the City of Brockton the rubbish was to be low in or devoid of garbage, and was to be supplemented by garbage from the City's separate garbage collection system. The rubbish and garbage were to be proportioned on the truck, 9 parts rubbish: 1 part garbage, and further mixed by bulldozer on the floor in front of the conveyor.

The next 24 hours of operation were to be at 3/4 full rating, followed by 24 hours of ½ rating. On the fifth day of the week there were to be 8 hours of start and stop operation to evaluate the unit under those conditions.

During daylight hours of each day the stack gases were to be sampled by Wisconsin Chemical and Testing Company (WC&T) to determine the loadings of particulate matter. The gases were also to be analyzed. The efficiency of the gas washer was not under investigation.

At the end of the test the inside of the combustion unit was to be examined to determine the condition of the refractory.

The Graham Research Laboratory of the Jones & Laughlin Steel Corporation (J&L) offered to assist on the operation of the furnace and to analyze the slag produced and the coke samples.

CONCLUSIONS

Conclusions were drawn from the test and evaluations in three categories:

a. In direct regard to the test objectives as based on the refuse fired and the operating techniques used by American Design and Development Corp.

b. From detailed technical analysis of the process, and

c. By pointing out opportunities and directions for further investigation and improvement.

1. In its state of development and method of operation during the March 1968 tests the pilot incinerator did not perform satisfactorily or reliably as evidenced by:

1. A. Low refuse firing rate. The best period of 6.5 hours had a refuse firing rate of 3200 lb per hr (1.6 tons per hr). It may not be practical to exceed this rate by more than 25-30 per cent without excessive entrainment of solids in the furnace gases. See pp 14-33.

1. B. High coke consumption relative to refuse incinerated. The most favorable rates were 8 tons of refuse per ton of coke during 6.5 hours and 6 tons of refuse per ton of coke for 11 hours. Too much air had been supplied to the coke bed. See pp 14-33.

1. C. Inability to drain molten iron and slag as necessary to maintain continuity of operation. The longest run was 62 hours during which 73 tons of refuse were charged. This run and others

ended with refusal of the slag and metal to drain. The molten residue was too viscous. During periods of good slag flow in Test A the slag temperature by immersion thermocouple averaged 2532 F, with a peak of 2650 F. See pp 14-33.

1. D. Limestone in the amount of 1 ton for 38 tons of refuse was used for promoting slag fluidity. Seven pounds of fluorspar were also used per ton of refuse, in an attempt to gain complete slag control. Fluorspar additions should not normally be required. See pp 14-33.

1. E. The emission of fly ash, including combustibles and ash was 288 lb an hour or more, roughly equal to 10 per cent of the refuse charged. See pp 52-62. Upwards of 25 per cent of the refuse inerts may thus not be converted to slag, unless reintroduced into the furnace in a manner that would insure melting rather than reentrainment in the gases.

1 F. High labor requirement (3 men per shift) to manage the furnace proper. High consumption of oxygen and iron pipe lances to maintain slag flow. See pp 16, 17.

1 G. The refractory furnace lining in the lower part of the coke bed was attacked by the high temperatures and slag ingredients. The lining in this critical area where the greatest refractory loss would occur, lost 2.5 inches on the furnace radius, as measured 12 inches above the lower air ports. The refractory in the upper part of the furnace had not deteriorated because the gas temperatures were seldom above 1900 F and usually below 1300 F during the test. See pp 62-63.

2. The molten residue from the Melt-Zit unit was free of putrescible and combustible matter of negligible solubility, that could be deposited in land fill without cover. It would not attract vermin or rodents, and it was odorless and sterile. The slag became a friable, black, glassy granulate when quenched in water. When cooled more slowly, it became a friable solid. It could also be flowed into dry molds and allowed to congeal and cool slowly in large masses. See pp C2, C3.

3. A high yield of iron from the refuse was produced in the form of spherical and flattened drops, when the molten slag was run into water. About 20 per cent of the melt weight was iron in this form, which could easily be seperated magnetically from the granulate. See p 50.

4. The electric power consumption of the pilot plant was 48.66 Kw per hr of operation. This quantity is not indicative of the power consumption to be expected in a full-scale installation. See p 64.

5. The water in the residue quench tank was cooled by circulation through a blower-cooled heat exchanger. Hence, furnace water consumption was the moisture on the granulate, about 14 gallons per ton of refuse. See p. C1.

6. The refuse burning rate is limited by the rate of melting of the inerts and/or by the loss of solids as carryover from the furnace. The carryover increases rapidly above 12 ft per second of gas velocity as loose paper, foil, plastic film wrappings, sweepings do not fall to the coke bed but are immediately carried upward from the charging chute. See pp 52-62.

Based on the tests, the burning rates for several sizes of incinerators would be as follows, scaled up in proportion to nominal diameter squared:

Furnace Diameter ft	Top Diameter ft	Tons refuse per hour
3	5	1.60 (Test B)
4	6.7	2.84
5	8.3	4.45
6	10.0	6.40
7	11.7	8.72

When improved performance can be demonstrated, the rated tonnages could be increased, probably up to 30 per cent. The tonnages could be increased until the amount of solids in the exhaust becomes intolerable. The tonnage capacity will decrease with lower refuse moisture content, as more air is required to burn the drier refuse and the entrainment of solids will increase. However, combustion will improve with drier refuse.

7. The Melt-Zit shaft furnace is only the primary combustion chamber of a complete incinerator plant. A secondary combustion chamber or chambers will be required to complete the combustion of the carry-over solids. A dust collector will be required after the secondary chamber to reduce the particulate loading of the exhaust gases. Such equipment was in existence at Whitman at the time of the tests.

8. Suggestions for the improvement of the Melt-Zit system are included in the section on Technical Evaluation. Additional tests are recommended.

9. Cost factors are discussed in the section on Economic Evaluation.

PERFORMANCE TESTS

General Results

On a nearby property City of Brockton rubbish and garbage were stockpiled separately in ample quantity prior to the start of tests, and covered with sheet plastic. The weather was cold enough to prevent putrefaction. Rubbish and garbage were mixed on the trucks by weight, prior to delivery to the plant.

The preliminary test began at 9:25 P.M. Thursday, March 14, 1968, and continued until 3:08 P.M. Saturday, March 16. During this period of 53.7 hours there were actually 11 operating hours during which only 10,128 lb of refuse were charged. Three separate runs were made to establish the desired screen arrangement at the top of the furnace and to correct mechanical problems. The planned objective of establishing the full-load capacity in advance of the main test was not achieved.

The main test period began at 8:37 A.M. Monday, March 18 and continued until 3:35 P.M. when it was necessary to drop the fire because of failure to maintain slag flow. 7 hour, 2517 lb refuse.

The second start of the main test period began at 10:25 A.M. March 19 and continued until 2:05 P.M. of the same day when the fire was dropped because of inability to keep slag flowing. 3 hr 40 min., 6680 lb refuse charged.

The third start of the main test runs began with ignition of the coke at 8:15 P.M., March 19, and ended at 3:37 P.M. March 22, when the fire was dropped because slag flow ceased and could not be restored. The time between ignition and drop was 67 hr and 22 min. The total hours between start and end of refuse charging (9:46 P.M. March 19 and 11:40 A.M. March 22) was 61.9 hours. The total refuse charged was 146,300 lb. The period was fraught with many problems; the basic one was extreme difficulty in maintaining slag flow because of high slag viscosity and low slag temperatures. The screen at the top of the furnace also accumulated enough ash, slag, metal foil and debris to offer excessive resistance to gas egress some of the time.

The other charges to the furnace during this run totaled

Coke	25,381 lb
Limestone	3,779 lb
Fluorspar	472 lb

Because of rainy weather the refuse was damp but not more so than experienced at times by other incinerator plants. Nevertheless, the high moisture content (38.45 %) imposed a thermal burden on the Melt-Zit unit beyond that of average refuse.

During the longest of the main test periods there were two periods of fairly steady operation, designated Run A and Run B in this report, and discussed in detail later. Run A was an 11-hr period with an average refuse charging rate of 2545 lb per hr.

Run B was a 6.5-hr period with an average refuse charging rate of 3200 lb an hr. This rating was the maximum achieved for any significant period. However, both runs ended with slag difficulties.

In preparation for the fourth and last of the main runs, the screen at the top was replaced by a grating with 3.75 x 1-inch openings (77 % free area). The run began at 4:43 P.M. Saturday, March 23, and ended at 10 A.M. Sunday, March 24. By Saturday midnight, the end of the official test period, 5929 lb of refuse had been charged. The slag flow was good but the refuse charging rate did not exceed that of previous runs. There was no plugging of the screen, but the furnace temperature did not come up to previous levels because of higher ingress of air at the chute, as the result of less resistance at the screen.

During the testing periods the number of men used included 3 men on the operating floor, 1 man at the control console, 3 men on the coke and limestone detail, and 2 men on refuse and residue handling--a total of 9 men per shift.

Neither the scheduled continuous 48-hr preliminary period nor the 96-hr main period were achieved. The maximum refuse charging rate was 1.6 tons an hr, and the most favorable coke rate was 1 ton of coke for 8 tons of refuse.

Start-and-stop experience was gained. On March 20 and on March 21 after the frit conveyor stalled, the forced draft blowers were shut off and the coke fire was banked for 33 minutes. When the blowers were restarted, the slag flow and operation resumed. On March 21 operation was restored after the blowers had been off for 3 hours.

8

By means of oxygen lances, rodding of air ports, fluorspar addition, coke and limestone charging, but no refuse feed, the slag flow was also restored on several occasions. Of course, the refuse feeding could be started and stopped at any time when the coke bed was in operating condition. However, the refuse feeding rate was restricted until the refractory walls were incandescent. Coke burning alone did not keep the shaft hot enough because of the cooling effect of the chute air, for which there was no damper.

Five tests for concentration of particulate emissions in the furnace gases 5 ft from the top of the shaft were accomplished by WC&T. Smoke, gas odor, sulfur and nitrogen oxide concentrations were also determined. The particulate matter captured during the 5 dust tests was analyzed and sieved.

The furnace refractory lining was examined and measured at the start of the main runs. The lining was generally unaffected, but the attack by slag and flux eroded away and enlarged the lower lining from 43 inches diameter to 48 inches.

The weights of refuse loads and the time of start and stop of loads into the furnace were recorded. The individual coke, limestone and fluorspar charges were weighed and entered in the notebooks. The coke air and refuse air flows from the blowers were measured by orifice meters and water manometers. The air humidity and temperature were noted.

Refuse and coke were sampled during the better operating periods, and analyzed. Forty-one samples of slag and metallic inclusions were taken and analyzed by the staff of the Jones and Laughlin Steel Corporation, in addition to those taken by the New York group.

Temperatures of blower exhaust air, furnace lining, and exterior furnace shell were measured by chromel-alumel thermocouples. Slag temperature was measured by optical pyrometer and by immersion noble-metal thermocouple.

The technical sections of the report will present and interpret the data. Further detail is given in the Appendix.

Best Operating Runs

The technical performance potentials of the Melt-Zit principle can best be judged from two periods of fairly steady operation during the main 67.4-hour run. These periods began when the furnace was producing slag freely and ended with the necessity to stop regular refuse charging while the furnace difficulty was being corrected.

The first of the steady operating periods was from 3 A.M. to 2 P.M. March 20 or 11.0 hours, and is designated Run A. The second such period, designated Run B, was between 6:30 P.M. March 21 and 1:00 A.M. March 22, or 6.5 hours. The two best runs were studied in detail as presented in the following pages.

The method of material and heat balances was used to present the results. The weights of refuse, coke, limestone, fluorspar and air charged must equal the weights of flue gas, fly ash, and slag and metal tapped. Likewise, the heat contents of the input materials must equal the heat contents of the output products. The material and heat balances combine the test data and provide and engineering accounting of the Melt-Zit process. With the aid of such balances one can draw conclusions about the potentials of the process and the directions in which improvement might be made.

Both Runs A and B are presented and analyzed in that way in the following pages. The analyses of the refuse and coke are from samples taken during the test, and are given in Appendix A.

Sources of methods and data are given in the section on References and Bibliography.

Run A

The log of Run A is shown in Figures 2 and 3. The cumulated weights of refuse, coke, and limestone charged are graphed against time in Figure 2. The charging rates were reasonably steady. The attempt to increase the refuse rate between 10:30 and 11:30 A.M. was unsuccessful, and it was necessary to discontinue feeding refuse for 30 minutes until normal conditions were re-established. The forced air supply for coke and refuse were nearly constant for the first 9 hours of the 11-hour run. The increase in forced coke air and the decrease in forced refuse air marked the beginning of operating difficulties leading to the end of a steady run. The run ended when slag stopped flowing from the spout, despite the use of fluorspar. However, slag flow was restored after Run A without shutdown.

The total of charges during the 11-hr period was refuse 28,000 lb; coke 4300 lb, limestone 825 lb and fluorspar 56 lb. During the more favorable periods the slag temperature by immersion thermocouple ranged from 2370 F to 2650 F, with an average of 2532 F.

The material and heat balances correlate the data obtained by the two observer teams and by the physical and chemical analyses. Additional information was derived from the balances, and is summarized as follows: Details in Appendix B.

The actual velocity of the gases approaching the top screen, 60-inch diameter = 945 fpm, or 15.8 fps. The actual velocity through the screen itself exceeded 1200 fpm.

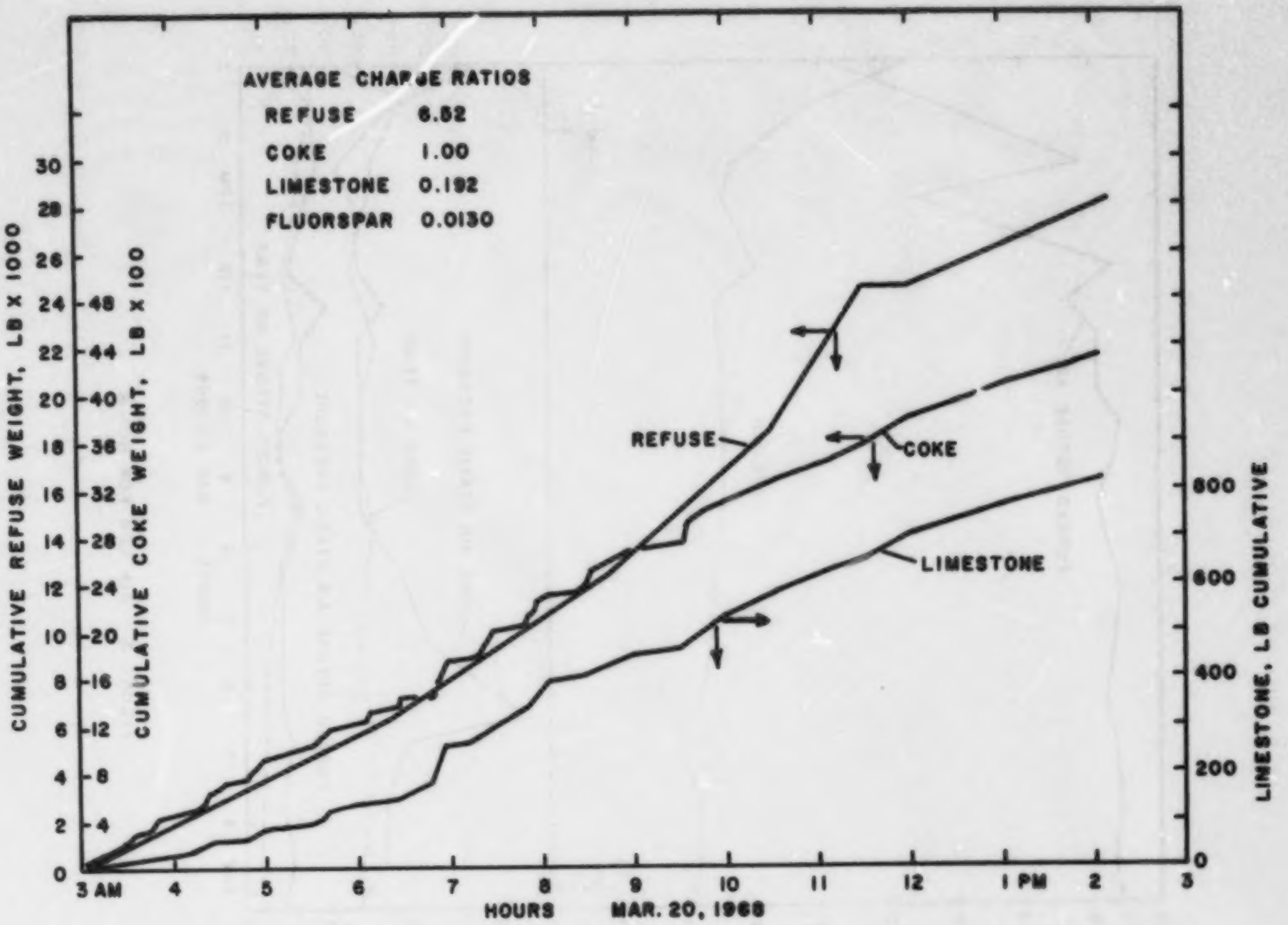

FIGURE 2. LOG OF RUN A.

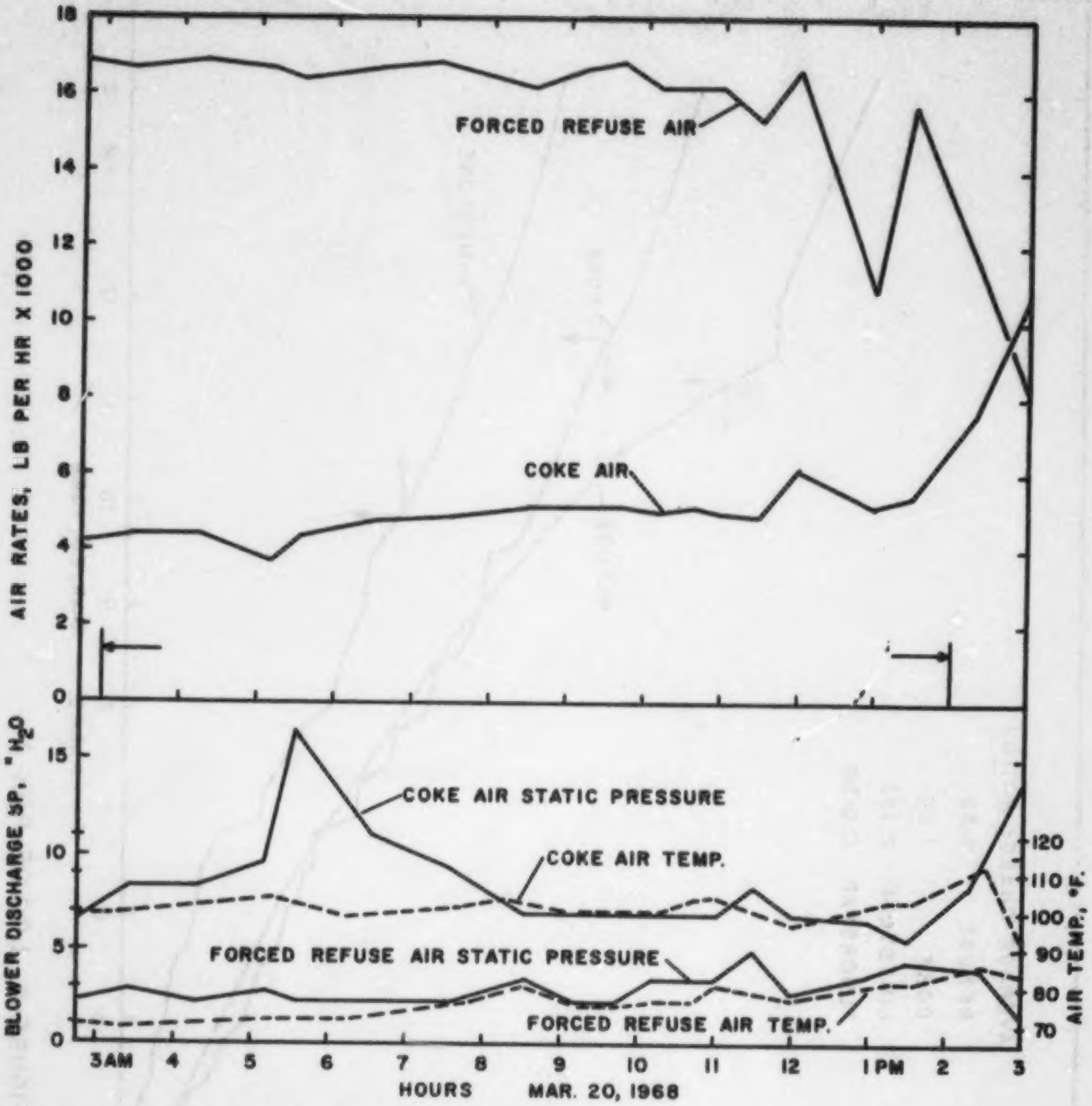

FIGURE 3. AIR LOG FOR RUN A.

TEST RUN A

3:00 A.M. to 2:00 P.M. March 20, 1968

11 Hours

MATERIAL BALANCE (1)*

INPUT			Lb per Hr
Refuse	28,000 lb/11.0, as charged		2,545
Moisture	38.45 %	979 lb	
Carbon	18.12	461	
Hydrogen	2.44	62	
Oxygen	14.24	363	
Nitrogen	0.24	6	
Sulfur	0.05	1	
Metal	4.85	123	
Inerts	21.61	550	
	100.00 %	2,545 lb	
Coke	4,300 lb/11, as charged		391
Moisture	7.64 %	29.8 lb	
Carbon	83.99	328.4	
Hydrogen	0.29	1.1	
Oxygen	0.97	3.8	
Nitrogen	0.04	0.2	
Sulfur	0.54	2.1	
Ash	6.53	25.6	
	100.00 %	391.0 lb	
Limestone	825 lb/11, as charged		75
CO_2	44 %	33 lb	
CaO	56	42 lb	
	100 %		
Fluorspar, CaF_2	56/11, as charged		5
Dry air			23,200
Coke air	4,900 lb, as metered		
Refuse air	16,000 , as metered		
Chute air	2,300 , by difference		
	23,200 lb		
Air moisture, 0.0065 lb/lb dry air, by psychrometer			151
	Total input, lb/per hr		26,367

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* References at end of report, before Appendix.

TEST RUN A

3:00 A.M. to 2:00 P.M. March 20, 1968

11 Hours

MATERIAL BALANCE, Continued

OUTPUT			Lb per hour
Dry stack gas leaving screen			23,455
CO_2		2,381 lb	
CO		24	
O_2		3,434	
N_2		17,616	
Water vapor in stack gas leaving screen			1,724
Fly ash in stack gas, as measured			288
Carbon	42.71 %	112 lb	
Hydrogen		1	
Oxygen		10	
Ash	57.29	165	
Dry gas leaving tap hole, calculated as orifice			308
CO_2	(Assumed	90 lb	
CO	at	0	
O_2	stoichiometric	0	
N_2	combustion)	218 lb	
Slag from tap, inerts charged + oxidized metal less ash in fly ash			474
Metal from tap, based on charges and analysis			118
Total output, lb per hr			26,367

TEST RUN A

3:00 A.M. to 2:00 P.M. March 20, 1968

11 Hours

HEAT BALANCE (1)

Base: 60F, water as liquid

INPUT	Btu per Hr
Heating value of refuse (HHV), 2545 (3,138)	7,986,210
Heating value of coke (HHV), 391 (12,343)	4,826,113
Heat of oxidation of iron to FeO, (Ref. 2) 3(2160)	6,480
Heat of oxidation of aluminum to Al_2O_3, (Ref. 2) 5(13,350)	66,750
Heat of vaporization of air moisture, from steam tables 151(1059.9)	160,045
Air preheat by blowers 4900(0.24)(102-60) + 16,000 (0.24)(77-60)	114,672
Total input, Btu per hr	13,160,270

OUTPUT	
Enthalpy of dry gas at 1270 F: 23,455(315), adjusted	7,374,397
Superheat of water vapor at 1270 F: 1724(1675.3-1088)	1,012,505
Heat of vaporization of water, 1724(1059.9)	1,827,268
Sensible heat in fly ash, 288(0.25)(1270-60)	87,100
Chemical heat of unburned combustible in fly ash	1,624,000
Chemical heat of carbon monoxide, 24(4347)	104,100
Heat of calcination of limestone, 75(780) (Ref. 3)	58,500
Enthalpy of molten slag at 2500 F (Ref. 3, 4)	326,000
Enthalpy of molten metal at 2500 F (Ref. 3, 4)	61,400
Enthalpy of gas from tap at 2800 F (Ref. 5)	236,000
Heat loss by radiation from screen (Ref. 6)	300,000
Heat loss from furnace casing (Ref. 7)	149,000
Total output, Btu per hr	13,160,270

Stack gas analysis:		Volume, %		Weight, %	
		Wet	Dry	Wet	Dry
Run A	CO_2	6.10	6.84	9.46	10.15
	CO	0.09	0.10	0.10	0.10
	O_2	12.13	13.60	13.63	14.62
	N_2	70.85	79.46	69.96	75.13
	H_2O	10.83	-	6.85	-
		100.00	100.00	100.00	100.00

Orsat analyses of the flue gas indicated a range of CO_2 contents from 3.0 to 10.8 % by dry volume. The lower amount occurred when only coke was being burned. At such times, as when the refuse feed was halted temporarily, the combustion gases from the coke bed were highly diluted by forced refuse air and by chute air. Hence, the percentages of excess air ranged from 79 to 521, depending on the amount of refuse being charged. When the screen at the top of the furnace was nearly clogged, the chute air fell to zero and the excess air with refuse feed on fell to 15%.

The average exit gas temperature was only 1270 F because of high excess air, equal to 182 % of the air actually used for combustion. The excess air could not be reduced because the refuse chute was wide open to admit building air. Higher temperature would have increased the refuse combustion rate.

The refuse charging rate was 360 lb an hour per sq ft of the furnace area at the 3 ft throat, which is about 6 times the rate for municipal incinerators.

The heat release rate in the combustion space above the coke bed was, for refuse alone, 6,446,310/645 = 10,000 Btu per cu ft-hr. Burning rates of up to 20,000 Btu/cu ft-hr are experienced in the primary furnaces of municipal incinerators.

The fly ash emitted was almost 10 per cent of the refuse and coke charged, compared with 2 to 3 per cent loss from the primary furnaces of conventional incinerators.

Run B

Figure 4 is a graph of the cumulated charges of refuse, coke and limestone for Run B. The refuse feeding rate was fairly constant but the coke and limestone rates gradually increased during the run. The supply rates for the coke air and forced refuse air, Fig. 5, were somewhat irregular but generally increased during the run until the last half hour. The run ended with the slag not flowing. The total of charges during the 6.5-hr period was refuse 20,800 lb, coke 2600 lb, limestone 480 lb and fluorspar 23 lb. The slag temperatures were similar to those of Run A.

The exit gas temperature was 1660 F, which was 390 F higher than in Run A. The excess air was 92 per cent or about half that of Run A. The refuse burning rate was 25.7 % higher as the result of more rapid ignition in a hotter furnace and hence more stable operation. The refuse rate was limited by the partial clogging of the screen, which limited the draft and hence the ingress of air through the refuse chute.

The refuse burning rate was 454 lb an hr per sq ft of shaft cross-section which is 7.5 times that of conventional incinerators. The refuse heat release rate was 8,182,010/645 = 12,700 Btu per cu ft-hr, but despite this conservative rate, the fly ash contained 57 per cent combustible. The high emission rate of solids in the gases would be a limiting factor on the rating. The fly ash equalled almost 10 per cent of the refuse and coke together.

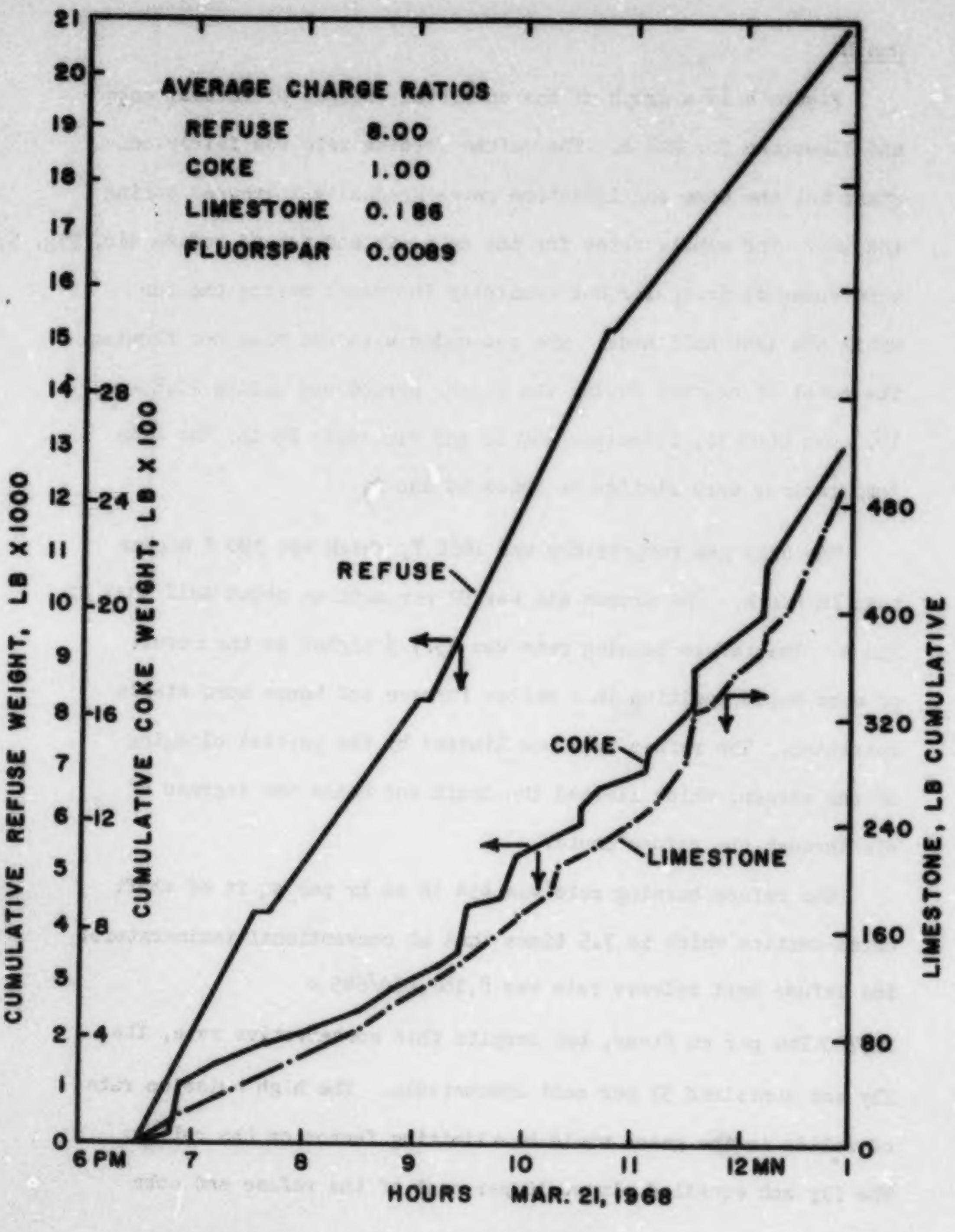

FIGURE 4. LOG OF RUN B.

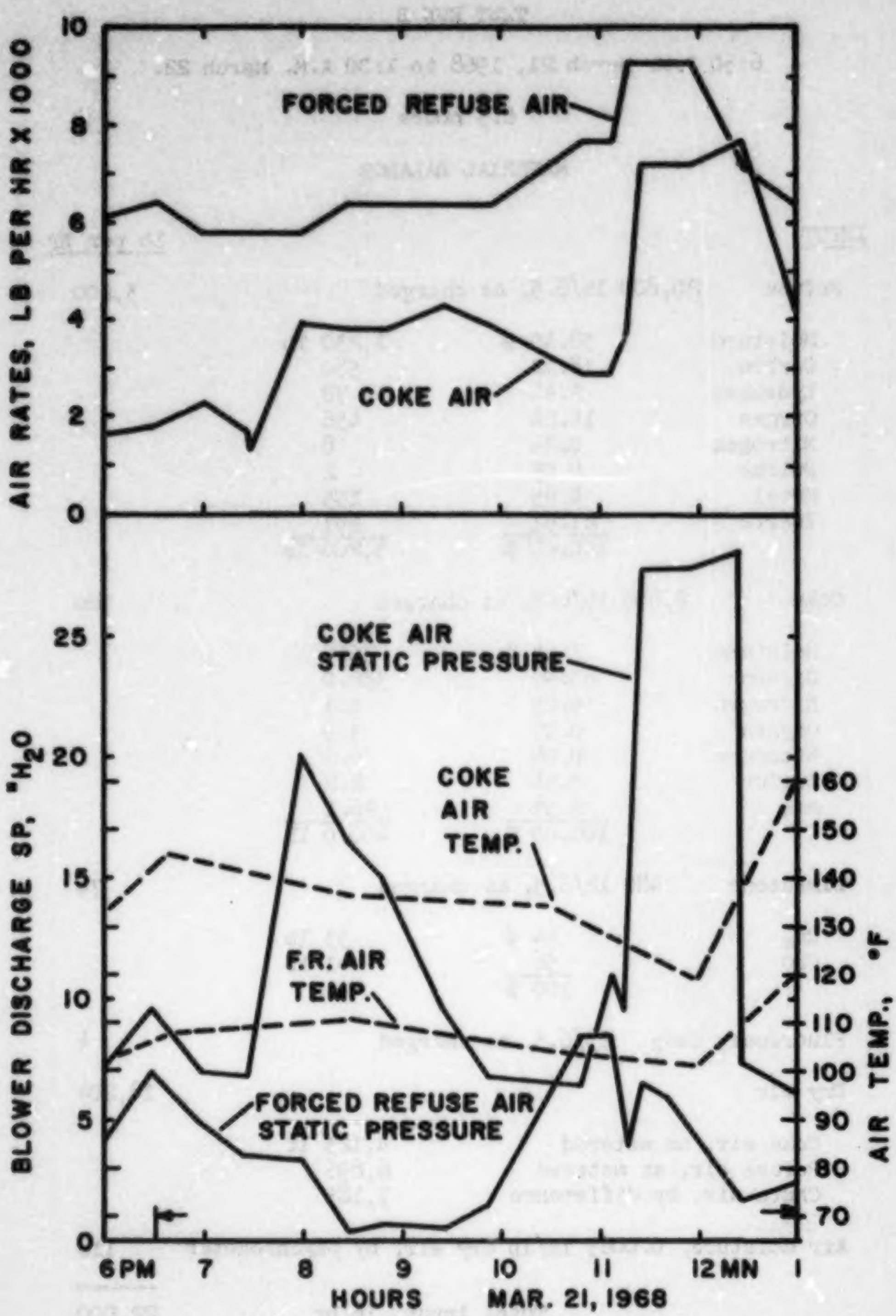

FIGURE 5. AIR LOG FOR RUN B.

TEST RUN B

6:30 P.M. March 21, 1968 to 1:00 A.M. March 22.

6.5 hours

MATERIAL BALANCE

INPUT			Lb per Hr
Refuse	20,800 lb/6.5, as charged		3,200
Moisture	38.45 %	1,230 lb	
Carbon	18.12	580	
Hydrogen	2.44	78	
Oxygen	14.24	456	
Nitrogen	0.24	8	
Sulfur	0.05	2	
Metal	4.85	155	
Inerts	21.61	691	
	100.00 %	3,200 lb	
Coke	2,600 lb/6.5, as charged		400
Moisture	7.64 %	30.5 lb	
Carbon	83.99	336.0	
Hydrogen	0.29	1.1	
Oxygen	0.97	3.9	
Nitrogen	0.04	0.2	
Sulfur	0.54	2.2	
Ash	6.53	26.1	
	100.00 %	400.0 lb	
Limestone	480 lb/6.5, as charged		74
CO_2	44 %	33 lb	
CaO	56	41 lb	
	100 %		
Fluorspar, CaF_2	23/6.5, as charged		4
Dry air			18,204
Coke air, as metered		4,123 lb	
Refuse air, as metered		6,896	
Chute air, by difference		7,185	
Air moisture, 0.0065 lb/lb dry air, by psychrometer			118
		Total input, lb/hr	22,000

TEST RUN B

6:30 P.M. March 21, 1968 to 1:00 A.M. March 22.

6.5 hours

MATERIAL BALANCE, Continued

OUTPUT				**Lb per Hr**
Dry stack gas leaving screen				18,533
CO_2			2,741 lb	
CO			30	
O_2			1,982	
N_2			13,780	
Water vapor in stack gas leaving screen				2,075
Fly ash in stack gas leaving screen, as measured				350
Carbon	139 lb	43 %	150	
Hydrogen	1 lb			
Oxygen	10 lb			
Ash		57 %	200 lb	
Dry gas leaving tap hole, calculated as orifice				308
CO_2		(Assumed	90 lb	
CO		at	0	
O_2		stoichiometric	0	
N_2		combustion)	218 lb	
Slag from tap, inerts charged + oxidized metal less ash in fly ash				586
Metal from tap, based on charges and analysis				148
Total output, lb per hr				22,000

TEST RUN B

6:30 P.M. March 21, 1968 to 1:00 A.M. March 22.

HEAT BALANCE

Base: 60F, water as liquid

INPUT

	Btu per Hr
Heating value of refuse (HHV), 3200 (3,138)	10,041,600
Heating value of coke (HHV), 400 (12,343)	4,937,200
Heat of oxidation of iron to FeO, 4 (2160)	8,640
Heat of oxidation of aluminum to Al_2O_3, 6.3 (13,350)	84,105
Heat of vaporization of air moisture, 118 (1059.9)	125,000
Air preheat by blowers, 4123 (0.24) (135-60) = 74,214 6896 (0.24) (105-60) = 74,477	148,691
Total input, Btu per hr	15,345,236

OUTPUT

Enthalpy of dry gas at 1660F	7,886,003
Superheat of water vapor at 1660F: 2,075(1890.8-1088)	1,665,810
Heat of vaporization of water, 2,075(1059.9)	2,199,293
Sensible heat in fly ash, 350(0.28)(1600-60)	151,000
Chemical heat of unburned combustible in fly ash, 139(14,300)	1,990,000
Chemical heat of carbon monoxide, 30(4,347)	130,410
Heat of calcination of limestone, 74(780)	57,720
Enthalpy of molten slag at 2500F	403,000
Enthalpy of molten metal at 2500F	77,000
Enthalpy of gas from tap	236,000
Heat loss by radiation from screen	400,000
Heat loss from furnace casing	149,000
Total output, Btu per hr	15,345,236

Additional information was derived from the balances and is summarized as follows: Details in Appendix B.

The actual velocity of the gases approaching the top screen, 60 inch diameter = 957 fpm, 16 fps. The actual velocity through the screen exceeded 1200 fpm or 20 fps.

Stack gas analysis:

	Volume, %		Weight, %	
	Wet	Dry	Wet	Dry
CO_2	8.48	10.07	13.30	14.79
CO	0.15	0.18	0.15	0.17
O_2	8.48	10.07	9.62	10.69
N_2	67.09	79.68	66.86	74.35
H_2O	15.80	-	10.07	-
	100.00	100.00	100.00	100.00

TECHNICAL STUDY OF MELT-ZIT PROCESS

Coke Bed

The performance tests indicated the need for better mechanical control of the process, lower coke consumption to reduce the cost of operation, and lower slag viscosity. This section of the report discusses the thermal process in the coke bed. Finally, the technical limitations are indicated for the process as regards coke consumption and production of slag and hot metal.

The overall process heat and material balances leave unanswered important questions about the reasons for the performance, and how it could be improved. To investigate further, the probable heat and material balances of the coke beds alone were calculated under the condition of refuse firing.

One objective was to determine the gas velocity leaving the coke bed, which governs the top size of particles that is entrained at that level. A second objective was to determine the relative amount of heat added to the residue by the coke to produce slag and metal. A third objective was to determine whether the coke consumption could be reduced.

The heat and material balances of the coke beds for Runs A and B were first developed, with appropriate estimates where actual data were not available. For example, it can reasonably be expected that some unburned char or carbon from the refuse is trapped in the bed by the coke and limestone charges, or burns on the surface of the bed as if it were coke. The amount was estimated. For the calculation of heat and material balances, the reader is referred to Reference 1.

TEST RUN A

MATERIAL BALANCE OF COKE BED

INPUT			Lb/per hour
Coke, as fired			391
Moisture	7.64 %	29.8 lb	
Carbon	83.99	328.4	
Hydrogen	0.29	1.1	
Oxygen	0.97	3.8	
Nitrogen	0.04	0.2	
Sulfur	0.54	2.1	
Ash	6.53	25.6	
	100.00 %	391.0 lb	
Char from refuse, estimated			100
Carbon		50 lb	
Ash		50 lb	
Limestone, as charged			75
CO_2	44 %	33 lb	
CaO	56 %	42 lb	
Fluorspar CaF_2, as charged			5
Remainder of residue from refuse			623
Oxides	550-50	500 lb	
Metal		123 lb	
Dry air, as metered			4,900
Air moisture at 0.0065 lb/lb dry air			32
Total input, lb per hr			6,126

TEST RUN A

MATERIAL BALANCE OF COKE BED, Continued

OUTPUT			Lb per hour
Dry gas from top of bed			5,163
CO_2	(378.4-8-2-50)3.667+33-90	=1,110.4 lb	
CO	50(28/12)	= 116.5	
H_2		2.3	
O_2		385.9	
N_2	4900(0.7685)+0.2-218	=3,547.9	
Water vapor			47
Fly ash, estimated			16
Carbon	50 %	8 lb	
Hydrogen			
Oxygen			
Ash	50 %	8 lb	
Dry gas from tap hole, calculated as orifice			308
CO_2	(Assumed	90 lb	
CO	at	0	
O_2	stoichiometric	0	
N_2	combustion)	218 lb	
Slag from tap, inerts charged + oxidized metal less ash in fly ash			474
Metal from tap, based on charges and analysis			118
Total output, lb per hr			6,126

TEST RUN A

HEAT BALANCE OF COKE BED

Base: 60 F, water as liquid

INPUT	Btu per Hr
Heating value of coke (HHV), 391(12,343)	4,826,113
Heating value of refuse char (HHV), 100(0.50) 14,093	704,650
Enthalpy of solids from refuse at 1500 F: 723 (0.233)(1500-60)	243,000
Heat of oxidation of iron to FeO, 3(2160)	6,480
Heat of oxidation of aluminum to Al_2O_3, 5(13,350)	66,750
Heat of vaporization of air moisture, 32(1059.9)	33,917
Air preheat by blower, 4900(0.24)(102-60)	49,392
Total input, Btu per hr	5,930,302

OUTPUT	
Enthalpy of dry gas leaving top of bed at 2620 F: 5163(708)	3,645,427
Superheat of water vapor at 2620 F: 47(0.547)(2620-60)	65,700
Heat of vaporization of water, 47(1059.9)	49,815
Sensible heat in fly ash at 2000 F: 16(0.25)(2000-60)	7,760
Chemical heat of unburned combustible in fly ash, 8(14,093)	112,744
Chemical heat of carbon monoxide, 116.5 (4,347)	506,426
Chemical heat of hydrogen, 2.3(61,100)	140,530
Heat of calcination of limestone, 75(780)	58,500
Enthalpy of molten slag at 2500 F	326,000
Enthalpy of molten metal at 2500 F	61,400
Heat loss by radiation from top of coke bed	700,000
Enthalpy of gas from tap at 2800 F	236,000
Heat loss from furnace casing around coke bed	20,000
Total output, Btu per hr	5,930,302

Actual velocity of gases leaving the top of the coke bed, 40 inches diameter = 731 fpm. = 12.2 fps. This velocity is sufficient to lift some fly ash but it is 23 per cent less than the velocity at the furnace top.

Calculated analysis of gas leaving coke bed before addition of forced refuse air:

	Volume, %		Weight, %	
	Wet	Dry	Wet	Dry
CO_2	14.65	14.88	21.31	21.50
CO	2.43	2.47	2.24	2.26
H_2	0.67	0.68	0.04	0.04
O_2	7.05	7.16	7.41	7.48
N_2	73.67	74.81	68.10	68.72
H_2O	1.53	-	0.90	-
	100.00	100.00	100.00	100.00

Coke burning rate per sq ft of horizontal area at top of coke bed: 391/8.74 = 44.8 lb/sq ft-hr, which is not high enough to cause an important loss of coke particles to the space above.

Heat release rate per cu ft of coke bed

4,826,113/35 = 137,888 Btu per cu ft-hr.

The temperature of the gases (2620 F avg) leaving the coke bed varied with time because cold coke and limestone were charged periodically. However, one would expect tin cans, wire, glass, and aluminum to melt high in the coke bed. The heat released by the coke was 10 times as much as required to melt the slag ingredients and the metal. The heat losses to the wall of the coke bed are largely recaptured by the windboxes. Most of the heat loss is in the gases from the coke bed. The melting temperatures are achieved by the burning of coke carbon to carbon dioxide with near stoichiometric air.

TEST RUN B
MATERIAL BALANCE OF COKE BED

INPUT			Lb per hour
Coke			400
Moisture	7.64 %	30.5 lb	
Carbon	83.99	336.0	
Hydrogen	0.29	1.1	
Oxygen	0.97	3.9	
Nitrogen	0.04	0.2	
Sulfur	0.54	2.2	
Ash	6.53	26.1	
	100.00 %	400.0 lb	
Char from refuse			100
Carbon		50 lb	
Ash		50 lb	
Limestone			74
CO_2	44 %	33 lb	
CaO	56 %	41 lb	
Fluorspar CaF_2			4
Residue from refuse			796
Oxides	691-50	641 lb	
Metal		155 lb	
Dry air			4,123
Air moisture at 0.0065 lb/lb dry air			27
		Total input, lb per hr	5,524

TEST RUN B

MATERIAL BALANCE OF COKE BED

OUTPUT			Lb per hour.
Dry gas from top of bed			4,438
CO_2		1024.0 lb	
CO	80(28/12)	187.0	
H_2		4.4	
O_2		272.0	
N_2		2950.7	
Water vapor			28
Fly ash			16
Carbon	50 %	8 lb	
Hydrogen			
Oxygen			
Ash	50 %	8 lb	
Dry gas from tap hole			308
CO_2		90 lb	
CO			
O_2			
N_2		218 lb	
Slag from tap			586
Metal from tap			148
	Total output, lb per hr		5,524

TEST RUN B

HEAT BALANCE OF COKE BED

Base: 60 F, water as liquid

INPUT	**Btu per Hr**
Heating value of coke (HHV), 400(12,343)	4,937,200
Heating value of refuse char (HHV), 100(0.50)14,093	704,650
Enthalpy of solids from refuse at 1500 F: 796 (0.233)(1500-60)	267,500
Heat of oxidation of iron to FeO, 4(2160)	8,640
Heat of oxidation of aluminum to Al_2O_3, 6.3(13,350)	84,105
Heat of vaporization of air moisture, 27(1059.9)	28,617
Air preheat by blowers	74,214
Total input, Btu per hr	6,104,926
OUTPUT	
Enthalpy of dry gas leaving top of bed at 2760 F: 4438(752)	3,337,696
Superheat of water vapor at 2760 F: 28(0.550)(2760-60)	41,600
Heat of vaporization of water, 28(1059.9)	29,677
Sensible heat in fly ash at 200 F: 16(0.25)(2000-60)	7,760
Chemical heat of unburned combustible in fly ash, 8(14,093)	112,744
Chemical heat of carbon monoxide, 187(4,347)	812,889
Chemical heat of hydrogen 4.4(61,100)	268,840
Heat of calcination of limestone, 74(780)	57,720
Enthalpy of molten slag at 2500 F: 586(0.282)(2500-60)	403,000
Enthalpy of molten metal at 2500 F: 148(520)	77,000
Heat loss by radiation from top of coke bed	700,000
Enthalpy of gas from tap at 2800 F	236,000
Heat loss from furnace casing around coke bed	20,000
Total output, Btu per hr	6,104,926

Actual velocity of gases leaving the top of the coke bed.

40 inches diameter = 656 fpm, 11.0 fps.

Calculated analysis of gas leaving coke bed before addition of forced refuse air:

	Volume, %		Weight, %	
	Wet	Dry	Wet	Dry
CO_2	15.75	15.92	22.93	23.08
CO	4.54	4.59	4.19	4.22
H_2	1.49	1.51	0.10	0.10
O_2	5.78	5.84	6.09	6.12
N_2	71.38	72.14	66.06	66.48
H_2O	1.06	-	0.63	-
	100.00	100.00	100.00	100.00

Coke burning rate per sq ft of horizontal area at top of coke bed

400/8.74 = 45.8 lb per sq ft-hr.

Heat release rate per cu ft of coke bed

4,937,200/35 = 141,063 Btu per cu ft-hr.

In Runs A and B the coke beds generated carbon monoxide and hydrogen, which represented losses of heat for melting residue at the expense of coke consumed. The carbon monoxide and hydrogen were burned by the forced air that was blown over the coke bed. Carbon dioxide was produced by the calcination of the limestone.

Additional information was derived brom the balances and is summarized as follows: Details in Appendix B.

Because of a closer balance of coke air rate with requirements, the temperature of the gases leaving the coke bed was 140 F higher in Run B than in Run A. A clean coke bed will generate over 3000 F within a short distance of the air ports (8), but viscous slag flowing over the coke will keep air from coke surfaces. The heat available to melt the slag ingredients and metal was over 10 times that actually absorbed by these materials.

These calculations of the Run A and B coke beds indicate that an ample amount of coke was being burned to have produced a fluid slag. The ratio of slag and metal to coke was:

Run A	592 to 391	or	1.51 to 1.0
Run B	734 to 400	or	1.83 to 1.0

A lower hourly rate of coke charged and a lesser amount of coke air should be possible for the same weight of residue. The slag flowed more freely during Run B than Run A despite a higher slag and metal output per unit coke burned.

As the low amount of limestone added was possibly incapable of fluxing the slag sufficiently, it was deemed advisable to investigate slag viscosity as a function of slag composition. The findings are discussed in the following section of this report.

Slag Composition and Viscosity

Successful operation of a slagging type of incinerator depends on the production of a slag of low viscosity, so that it will drain freely from the fuel bed and furnace. When the slag does not flow readily in a coke bed, the burning rate decreases, air flows through channels, the slag chills, and a complete freeze-up occurs. To decrease the slag viscosity, a furnace operator depends on a favorable slag composition and on high temperatures. The production of a thick slag was the major difficulty during the March 1968 tests.

Slags consist mainly of metal oxides and complex compounds formed between some of these oxides. Silica (SiO_2) is the most abundant oxide found in the non-combustible fraction of municipal refuse. Glass, which accounts for upwards of 40 per cent of refuse inerts, is 70-75 per cent silica. The viscosity of molten silica is very high. Molten aluminum oxide (Al_2O_3), iron oxide (FeO), titanium oxide (TiO_2) and phosphorus pentoxide (P_2O_5) tend to interlock with the structural network of a silicate slag, with an attendant increase in viscosity. These are also present in refuse mineral matter.

Other metal oxides in refuse, such as those of sodium, potassium, calcium, and barium and to a lesser extent, magnesium, and iron, can reduce the viscosity of the "long molecule" silicate slag by producing a "short-molecule slag"(9). Lime (CaO) is the ingredient commonly added as limestone to metallurgical furnaces to reduce the viscosity of silicate slags. In emergency use, fluorspar (CaF_2) is highly effective in making a major reduction in slag viscosity by additions of only 1-4 per cent of the slag weight.

A slag containing solid particles tends to be much more viscous than the liquid phase by itself, or than the same total composition would be if it were all liquid. The presence of solid particles would result if insufficient time is allowed for the slag to become homogeneous. There are saturation limits for an oxide constituent beyond which a solid phase results.

A viscosity of 5 poise is considered desirable (9) as the slag is then thin enough to drain readily from the coke, leaving coke surfaces free for combustion. (Glycerin has a viscosity of 5 poise at about 86 F.) A viscosity as low as 5 would not be necessary for the Melt-Zit process as the slag was considerably more viscous under the best flow conditions during the test. However, glass has a viscosity of 100 poise at 2600 F and 10,000 poise at 1900 F (10).

Unfortunately, the addition of limestone in sufficient quantity does not ensure rapid combination with the high-silica inerts, such as glass, in the upper portions of the coke bed. However, at the bottom of the coke bed where the slag flows laterally, or in a slag well at the base of the coke column, the blending could be completed so that the slag flow from the tap would be under control.

A reduction in the glass content of refuse, by whatever means, would alleviate the problem as the other refuse inerts would produce a less viscous slag. An increase in bed temperature would reduce the slag viscosity. A reduction in gas velocity in the coke bed would also reduce the drag forces that impede the downward flow of the slag by gravity.

The slag from the Melt-Zit process was mainly of the CaO-MgO-Al_2O_3-SiO_2 system. Other oxides were present in minor amounts, which had the effect of raising or lowering the viscosity as indicated above. The oxides of sodium, potassium and barium in refuse probably reduced slag viscosity more than the titanium and phosphorus oxides increased it.

From the material balance of Run B, the analyses of the slag by J&L , and fly ash analyses by WC&T , it was possible to derive weights of the total oxides in the fly ash and slag. The contributions to these totals by the limestone and coke, could be approximated from handbook data. The analyses for glass and the ash from the principle refuse components have also been published (11). Because the metal product was almost devoid of aluminum, it can be assumed that the aluminum in the refuse was oxidized in the furnace and appeared in the slag and fly ash. Some iron was also oxidized as revealed by the rather high iron oxide content of the slag. Hence, it was possible to derive a material balance of the oxide solids with sufficient accuracy to evaluate the slag problem.

The following Table 1 compares the resultant slag with other metallurgical slags (3, 4). The tables used to derive the Melt-Zit oxides balance are in Appendix C.

Table 1. Slag Compositions, in per cent

	Test Run B slag	Acid slag	Blast furnace slag	Open hearth slag
P_2O_5	0.74	--	--	--
SiO_2	62.37	63	35	19
TiO_2	0.67	--	--	--
Al_2O_3	7.58	10	15	5
Fe_2O_3	--	--	--	3
MgO	3.32	--	3	10
FeO	5.15	--	1	11
MnO	0.25	--	2	7
CaO	14.22	27	42	44
Na_2O+K_2O	3.75	--	--	--
Others	1.95	0	2	1
Total	100.00	100	100	100
CaO/SiO_2	0.23	0.43	1.2	2.3
$\frac{CaO+MgO+Na_2O+K_2O}{SiO_2+Al_2O_3+TiO_2+P_2O_5}$	0.30	0.37	0.90	2.25

Even with the limestone addition, Test Run B slag was an acid slag, and hence viscous.

A study of slag viscosity/ constitution diagrams (9) indicates the progressive reduction of slag viscosity with increase in lime content above that present in the Test B slag. To raise the lime content to a base/acid ratio of 0.9 would have required a total of 350 lb of limestone per ton of refuse. In view of the added expense for the limestone , the slow dispersion of the lime into the glass, and the additional slag for disposal, other solutions of the problem should be sought.

The increase of coke air temperature by preheating would elevate the entire coke bed temperature and would also aid in making the slag more fluid. The need is for higher temperatures and lower gas velocities in the coke bed. By preheating the coke air to 800 F or higher and reducing the coke ratio relative to refuse fired, the bed temperatures would be raised, the slag rendered more fluid, and the drag forces on the slag from gas flow also reduced.

Metal Inclusions in Slag

Refuse iron and steel were melted in the Melt-Zit unit and appeared with small loss in the form of rounded pellets in the frit. The molten furnace product was 20 - 23 per cent metal. The pellets alone had a specific gravity of 6.77, and a bulk density of 226 lb per cu ft.

The pellets were magnetic, file hard, and contained bubbles of gas. The Rockwell C hardness of 61 and the white brittle fracture indicated them to be white iron due to the formation of cementite, Fe_3C, during rapid chilling.

The chemical analyses of 8 samples taken during the test indicates the average composition given in Table 2. The ranges are given in Appendix D.

Table 2. Average Composition of Residue Metal

Iron	95.16 %	Molybdenum	0.02
Carbon, estim.	2.0	Nickel	0.2
Aluminum	0.03	Silicon	1.6
Chromium	0.3	Titanium	0.06
Copper	0.3	Tin	0.02
Manganese	0.20	Sulfur, estim.	0.1
Magnesium	0.01		100.00 %

Silver was present under 0.01 per cent.

Refuse aluminum was almost entirely converted to Al_2O_3 in the furnace and hence became part of the slag. Aluminum is readily oxidized by carbon dioxide, water vapor and free oxygen in a hot coke bed.

The metal is probably of satisfactory quality for melting furnaces in which the small particle size would not be objectionable. Magnetic separation would not be difficult. The yield would be about 4.6 per cent or more of the Brockton refuse, depending on the moisture content of the refuse.

If not salvaged, the metal would gradually rust in the landfill.

FURNACE EMISSIONS

The Melt-Zit unit was equipped with a refractory-lined flue gas offtake duct and a venturi gas scrubber. To permit proper sampling of the flue gas for particulate loading ahead of the gas scrubber as originally planned, it was necessary to discharge the gases directly to the atmosphere at the top of the furnace. It was recognized that carbonaceous solids and combustible gases would have continued to burn in the refractory-lined offtake. Furthermore, it was recognized that dust collectors of various types and efficiencies could be employed to reduce the particulate loadings before the gases would be discharged in commercial and municipal installations.

The top of the furnace was opened and covered with a stainless steel screen. The screen was an expanded metal mesh with diamond-shaped 1 x 5/16-inch openings and 59 per cent free area. The furnace top was 60 inches diameter. The screen did not fit tightly and suffered distortion from the heat. One purpose of the screen was to hold any oversized pieces of paper, etc., carried up by the gases until they were burned. Another purpose of the screen was to provide a degree of flow control as a means for balancing the total draft and air ingress to the furnace through the refuse chute.
This modification was a simulation of the "wet cap" gas washer that was used on the furnace prior to the venturi scrubber installation. The test had been planned on the basis of the wet cap.

In general, the furnace emitted a shower of particles of ash and burning matter, sometimes with flames up to 10 feet above the screen. Charred paper, particles of plastics, ash dust, metal foil and even razor blades were discharged.

The Wisconsin Chemical and Testing Co. determined the gas compositions, temperatures, velocities and concentrations of particulate matter by sampling through ports 5 feet from the top where the inside diameter was 57 inches. The air pollution studies were reported separately by WC&T, from which the following summary was derived.

The gases were analyzed by Orsat apparatus and a continuous CO_2 recorder. The gas velocities were measured by pitot-tube traverses on two diameters at right angles. The gas temperatures were measured by a small sheathed Cr-Al thermocouple in the gas stream. The particulate sampling was isokinetic by a 1.25-inch dia. nozzle, and conducted in accordance with the test procedures and equipment outlined and detailed in the American Society of Mechanical Engineers Power Test Code 27 - 1957, and the Air Pollution Control Association TA-3 Incinerator Committee Informative Report No. 2. Smoke, odor, SO_2, NO_x values were obtained by commonly accepted methods.

The sampling and analysis were conducted during daylight hours several times each day when the furnace was burning refuse, although a few readings were taken when only coke was being burned.

During a period of maximum refuse burning the resistance of the screen increased by partial plugging, causing a positive pressure at the sampling port. Sampling had to be discontinued at that time. Because refuse feeding was on and off at unpredictable intervals, the stack gases were affected immediately due to the suspension burning. A period of particulate or gas sampling was a composite of on and off refuse feeding.

The data were vital to the development of the material and heat balances and an understanding of the process. The measurement of the particulate emissions and velocities also was indicative of the limitations on burning rate, the need for secondary combustion space, and the burden on the dust collector.

Particulate Emissions

Five determinations of particulate loading of the gases were completed:

Dust Test No.	Date	Time	Mass Emission Rate, Lb/hr	Corrected to 50 % Excess Air, Lb/1000 lb gas
1	3-18-68	12:00-12:45 P.M.	151.0	13.88
2	3-18-68	3:00- 3:20 P.M.	223.5	23.72
3	3-19-68	1:19- 1:50 P.M.	246.0	13.07
4	3-20-68	9:10- 9:56 A.M.	288.0	18.77
5	3-20-68	2:05- 2:26 P.M.	385.2	28.80

The emission rates were for solids in the gases as the gases approached the screen, and were thus not physically affected by the screen.

The particulate loading of Dust Test 4 was during the mid-period of Run A and is most representative. Dust Test 5 was immediately following the end of Run A when the rate for coke air was somewhat higher than normal.

The collected particulate matter was dried, analyzed, and sieved in the laboratory, with results as given in Table 3.

Table 3. Analyses of Particulate Matter Emitted with Furnace Exhaust

Dust Test No.	1	2	3	4	5
Combustible, %	31.63	31.45	37.90	42.71	30.33
Ash, %	68.37	68.55	62.10	57.29	69.67
Acetone soluble, %	3.13	1.73	12.43	15.17	2.54
U. S. Sieve Size	Retained on Each Sieve Size, Per Cent				
8	4.29	2.55	5.57	7.10	2.81
20	22.24	25.92	18.01	31.00	35.62
60	27.67	41.03	28.33	39.54	42.92
100	13.20	10.52	14.60	9.27	8.77
200	13.24	10.05	13.71	6.25	4.58
325	6.75	4.03	6.84	2.63	1.56
<325	12.61	5.86	12.97	4.21	3.72
	100.00	99.96	100.03	100.00	99.98

The proportions of suspended solids from the coke, limestone and refuse are not known. Nevertheless, the weight loss in Test 4 was equal to 18.3 per cent of the weight of dry refuse charged. The ash content of the weight loss was equal to 26.9 per cent of the mineral matter, excluding metals, that were present in the refuse, coke and limestone charged.

The acetone-soluble portion indicates the presence of hydrocarbons in the combustible matter from the refuse. The combustible matter was only partially pyrolyzed to char in its transit through the furnace. The lower combustible and acetone-soluble fraction during Dust Test 5 was caused by less refuse firing and more coke burning during a distress period after Run A.

The sieve analysis of particulates was the result of a rather vigorous Ro-tap machine sieving for 10 minutes. The friable char was undoubtedly broken down somewhat while bouncing on the sieves. Nevertheless, the large size of the material by dust collection standards indicates that high collection efficiency could be expected if this material were to enter a gas scrubber. With secondary combustion to lower the combustible content, the particle sizes and weights would both decrease.

All Orsat gas analyses obtained by WC&T during the period of Test Run A are assembled in Table 4 with the data calculated from the material balances, based on weights over the entire Run A (3 A.M. to 2 P.M., March 20).

Table 4. Furnace Exit Gas Data from Test Run A

Time	A.M. 8:45	A.M. 9:10	A.M. 9:21	A.M. 9:10-56	A.M. 11:30	P.M. 2:08	From Balance
				Dry volume, per cent			
CO_2	8.0	6.7	7.2	7.36	10.75	10.4	6.84
CO	0.1	0.0	0.1	0.10	0.10	0.1	0.10
O_2	12.3	13.5	13.6	13.00	9.90	9.6	13.60
N_2	79.6	79.8	79.1	79.54	79.25	79.9	79.46
Temp. F	1440	920	1140	1081	1275	940	1270
Excess Air, %	140	178	184	161	89	83	182
Volume, cfm	26,220	-	-	-	20,600	-	18,500
Velocity, fpm	1483	-	-	-	1160	-	1062
Mass flow, lb/hr	32,900	-	-	-	28,800	-	20,608

The WC&T data above were from periods of refuse feeding, whereas the data from the balances also include periods when only coke was charged. When refuse is charged, the percent CO_2 is highest. When only coke was burned, as when the refuse feeding was stopped temporarily because of difficulty with slag control, WC&T measured 3.2 % CO_2 (Orsat) in the exit gases, with 3.0 % at times. The normal air supply to the furnace continued during the refuse feed interruption and lowered the CO_2 by dilution.

Similarly for Run B, Orsat gas analyses and other data are in Table 5 below for comparison with those calculated from heat and material balances, based on weights over the entire run, 6:30 P.M. March 21 to 1:00 A.M.

Table 5. Furnace Exit Gas Data from Test Run B

Time	P.M. 6:42	P.M. 6:53	P.M. 7:05	P.M. 7:10	From Balances
			Dry volume, per cent		
CO_2	17.75	7.2	11.0	10.0	10.07
CO	0.10	0.1	0.1	0.3	0.18
O_2	3.30	12.9	7.0	8.2	10.07
N_2	78.85	79.8	81.9	81.5	79.68
Temp. F	1950	1350	1870	1970	1660
Excess Air, %	18	157	47	60	92
Volume, cfm	24,500	-	-	-	18,770
Velocity, fpm	1380	-	-	-	1060
Mass flow, lb/hr	25,100	-	-	-	20,608

In view of the wide fluctuations in burning rates during Runs A and B, and the short sampling periods compared to the entire runs, the correlation of measured values with those from the balances is quite satisfactory.

Smoke

During the first three days of the main 5-day test, no blackness was observed in the exhaust gases, but a brownish to whitish cast was observed with an opacity not exceeding No. 3 Ringelmann equivalent. The same condition held during the last two days except for 5 or 6 short intervals daily of black smoke of No. 4 and

5 Ringelmann, but seldom over 1 or 2 consecutive minutes each. The smoke occurred when the screen was loaded, temperatures were high and excess air was low.

Orsat analyses taken during a smoking condition showed a high carbon dioxide (16.0 %) and carbon monoxide (1.4 %) content. The excess air at the time was only 12.9 per cent. These smoke conditions could be corrected in a secondary combustion chamber.

Sulfur Oxides

Sulfur oxides (SO_2+SO_3) in the stack gases were determined by the barium sulfate method during 5 periods, resulting in four determinations, and reported as sulfur dioxide in Table 6.

Table 6. Sulfur Oxides in Furnace Exit Gas, parts per million

Date	Time	Avg. gas Temp. F	Avg. SO_2, Vol. ppm
3/20/68	9:50 A.M.-10:30 A.M.	1352	65.6
	2:07 P.M.- 2:24 P.M.	1020	72.4
3/21/68	9:25 A.M.- 9:31 A.M.	2005	113.0
3/22/68	8:10 A.M.- 9:05 A.M.		
3/22/68	10:02 A.M.-10:50 A.M.	1900	49.9

The first two results were obtained during Run A, when the excess air was about 182 per cent. The hourly volume of dry gas was 298,000 cu ft. Hence the average SO_2 volume of 69.0 ppm would represent 20.6 cu ft of 60 F SO_2 per hr, or 3.56 lb per hr. The sulfur necessary to produce this SO_2 is 1.78 lb. As the refuse and coke together contained 7.2 lb, only 25 per cent of the sulfur was converted to SO_2 in the stack gas. This confirms an earlier finding for incinerators generally (12). The remainder of the sulfur will be found in the fly ash and in the tapped residue.

Oxides of Nitrogen

Four NO_x gas samples were taken on March 22 when the stack gas was consistently above 1900 F. The grab samples were taken and analyzed by WC&T following the phenoldisulfonic acid method. The findings are reported as nitrogen dioxide in Table 7.

Table 7. Nitrogen Oxides in Furnace Exit Gas, parts per million

	NO_2, ppm by volume	
Time	Dry basis	Wet basis
8:02 A.M.	105.9	98.0
8:05 A.M.	118.3	109.4
10:17 A.M.	105.0	97.1
10:27 A.M.	68.2	63.1

As the furnace was probably exhausting 200,000 cu ft of dry gas an hr at the time, 80 per cent nitrogen, the findings indicate that 13.6 to 23.7 cu ft of NO_2 were generated per hr. The concentrations of NO_x from the Melt-Zit unit were similar to those reported for other municipal incinerators and much less than those for large industrial boilers or automobiles (13).

Odor

The sampled gases were regularly checked for odor as they were discharged to atmosphere from the dust sampling apparatus. At no time during any of the five dustloading tests was there any detecable odor in the sampled gases.

The gas temperatures at the time of sampling ranged from 820 to 1320 F, which would ordinarily not destroy all odors. Nevertheless, other experience indicates that when good combustion prevails, as with incinerators that generate 1500 - 1800 F and have secondary combustion chambers, odor from stack gases is negligible.

REFRACTORY SERVICE

The shaft furnace consisted of a cylindrical shell lined with firebrick shapes to produce the contour shown in Figure 1. Before the tests began, the firebrick had a thin slag glaze from previous development trials.

The firebrick lining was inspected before the tests and again after the 67-hr main run. In general, the lining had the same appearance, with neither gain of slag nor loss of refractory, except for the 12-inch zone above the coke air ports.

Undoubtedly the hottest part of the coke bed was within 12 inches of the air ports and may well have reached 3000 F, with the refractory temperature several hundred degrees less. The slag was thinnest in the hottest zone and most conducive to penetrating and interacting with hot refractory. Fluorspar is also known to attack hot refractory by producing a lower melting slag with the refractory. Furthermore, when the coke air rate was varied quickly over a wide range or cut off entirely, the most rapid fluctuations in refractory surface temperatures occurred in the lower zone.

The net result was an increase in lining diameter from 43 to 48 inches, as measured on two diameters 12 inches above the bottom of the coke air ports. This change occurred over 3 periods totaling 78 hours of combustion when the furnace charges totaled 155,000 lb of refuse.

This rapid loss of refractory could not be tolerated in practice. However, it could probably be reduced or prevented by a redesign of the lower furnace zone to provide for a water-cooled jacket with thin refractory lining that would achieve a thermal equilibrium with the coke bed and slag. Also, hopefully, the need for fluorspar could be reduced to rare occasions.

The temperatures measured at the refractory surface near the chute level, but 90 degrees away from the chute, reached 1400 F for a short time, but were generally only 900 to 1100 F during the best runs. However, temperatures of 1800 to 2000 F could be expected when the overall excess air rate is brought under control at 100 to 150 per cent of stoichiometric for the total fuel and refuse charge. Refractories can operate indefinitely at these and higher temperatures when the latter are reasonably steady, but slag attack from refuse constituents that melt on the refractory gradually destroys refractory. The service life of refractory above the coke bed can only be determined over periods of a year or longer.

POWER REQUIREMENTS

The electric power demands of the blowers, pumps and conveyors of the pilot plant were measured during the test. As all of the equipment were not in use all of the time, the power consumption was calculated for normal operation, assuming a power factor of 85 per cent. The findings are listed in Table 8.

Table 8. Power Requirements, Demand and Use

	Demand, Kw	Use, Kwhr
Coke air blower, 40 hp	17.70	17.70
Refuse air blower, 30 hp	18.35	18.35
Refuse conveyor, 10 hp	6.48	5.50
Coke elevator, 3/4 hp	0.75	0.13
Coke feeder, 1/3 hp	0.33	0.06
Frit conveyor, ½ hp	0.50	0.50
Frit tank pump, 5 hp	4.60	4.60
Cooling tower fan, ½ hp	0.50	0.50
Building, other, 120 amp	1.32	1.32
Maximum, total	50.53 Kw	48.66 Kwhr

It is not advisable to use these data to predict the power consumption for a full-scale installation. Because of its experimental nature, the pilot installation was overpowered in some respects in proportion to tonnage throughput. Also, the pilot unit did not have a crane for moving refuse, nor was a dust collector in use. The power requirements of a full-scale plant could be predicted from manufacturer's data on equipment to be used on a complete installation.

TECHNICAL EVALUATION

The technical advantages of the Melt-Zit process are a residue free of putrescible matter, maximum density in landfill, minimum pollution of ground water or streams, possible salvage or use value of the residue, and minimum use of water.

The capacity, refuse/coke/limestone ratios, and labor for Melt-Zit furnaces cannot be fully evaluated from the March 1968 tests. The incinerator would undoubtedly perform better with modifications, such as additional air and feed controls, and others. Experience will also improve the skills of operators in managing the coke bed and furnace generally.

The methods used for conveying refuse, coke and residue will bear improvement. The top size of pieces of refuse must be limited to prevent clogging of the chute, or a method of mechanical feeding should be devised that will insure positive movement in the chute. The screw conveyor in an inclined trough jammed and had to be removed because all of the residue was not in the form of frit and small pellets. A flight conveyor in the same trough did not fare any better. An earlier type of angle-iron drag conveyor which extended across the entire bottom and slope of the residue quench tank had the capability of moving coarse and fine residue without difficulty.

During the test the feeding of refuse was halted 5 minutes every 30 minutes while coke was being charged and heated. Simultaneous and steady feeding of coke, limestone, and refuse was tried but was not successful, probably because the furnace lining above the coke was not hot enough to ignite the refuse promptly. The method should be tried again after the present furnace has been improved.

High viscosity of glass and other high silica inerts is a fundamental problem of the Melt-Zit furnace. The prior removal of glass for salvage as saleable cullet, or separate collection as practiced in some localities, would be helpful. An increase in coke-bed temperature through air preheat would be an economical method for reducing the slag viscosity. The addition of limestone should also be helpful in lowering slag viscosity, provided there is opportunity for the lime to mix with the glass. Higher temperatures are necessary for the lime to be fully effective.

Preheating of the coke air would be helpful, and is essential if the coke rates are to be reduced to a minimum. Ample excess heat is available. Each 100 F rise in blast temperature would raise the coke bed, slag, metal and gas temperature by about 35 F. Again, only experience will tell whether the effect will be sufficiently beneficial or whether the viscous zone will only move higher in the coke bed. A modest air preheat would probably not be worthwhile, but coke air at 800 F would be effective.

A decrease in coke rate to 1/25 of the refuse is theoretically possible, and a coke rate of 1/20 of the refuse may be feasible in practice, even with a high moisture refuse. However, a decrease in coke consumption will be accompanied by a higher ratio of metal, inerts, and limestone in the coke bed, and lower temperatures in the coke bed. Air and gas friction during upward flow in the coke bed resist the downward flow of slag. These factors oppose successful operation.

The loss of refractory experienced could not be tolerated in a municipal plant. In order to gain sufficient refractory life a thermal equilibrium layer between fluid slag and solid refractory is required. A method that has been used for slag-tap furnaces is forced cooling behind a relatively thin refractory.

Assuming that the above problems can be solved and demonstrated, one can estimate the capacities of similar furnaces of larger diameters. The upper limit in a circular furnace is a coke bed without a dead central core. A maximum practical diameter would probably be 10 feet, and possibly 8 or 9 feet. Furnaces of rectangular section are also possible.

A limit must be placed on the exit gas velocity, or the carry-over of burning paper and fly ash will place an excessive burden on the secondary chamber and dust collector, as well as to seriously reduce the amount of inerts converted to slag.

The test indicated that the primary furnace volumes required will be equal to those of conventional incinerators of the same capacities.

Excluding the metals, at least one-fourth of the mineral matter charged to the test furnace was blown out with the fly ash, with combustible in addition. The combustible could be largely burned out in a secondary combustion chamber of suitable size and design. The mineral matter would be caught, except for minor loss to the atmosphere, by the gas scrubber. The captured fly ash would have properties different from the slag, and would have to be reclaimed from the water.

Smoke from the Melt-Zit furnace may be expected at times as from the primary combustion chambers of conventional incinerators. A secondary combustion chamber will assist in smoke prevention.

If one assumes a maximum refuse rate of 4000 lb an hr for the test furnace of 3 ft throat diameter and 5 ft top diameter, the exit velocity will be close to 1000 fpm. The refuse analysis is assumed the same as during the March 1968 tests. The gas volume will be proportional to the refuse burned, but the furnace areas and refuse tonnages will increase as the diameters squared. On this basis projected tonnages for various furnace sizes are given in Table 9.

Table 9. Projected Refuse Tonnages and Coke Consumption

Furnace Throat, inside dia., ft	Coke Bed dia., ft	Furnace top inside dia., ft	Projected Refuse Input, tons/hr	Coke at 1:20 refuse, lb/hr	Coke at 1:8* refuse, lb/hr
3	3.6	5.0	2.00	200	500
4	4.8	6.67	3.58	358	895
5	6.0	8.34	5.55	555	1388
6	7.2	10.0	8.00	800	2000
7	8.4	11.67	10.9	1090	2725
8	9.6	13.35	14.2	1420	3550

*Test B

The above hourly charging rate for refuse is 393 lb per sq ft of coke bed which would be 25 per cent better than was accomplished during Run B of the test.

Improvements, tests, and studies suggested for the development of the Melt-Zit system include:

1. Preheating of the coke air to 800 F or more by waste heat from the exhaust of the secondary combustion chamber. The objective is to increase the heat available above the 2600 F datum. Preheat of the refuse air is not recommended except as it may aid under some conditions; furnace exhaust gas temperature should not exceed 1800 F, as a deterrent to slag deposits above the coke bed.
2. Refractory cooling around the coke bed to maintain the integrity of the refractory. Refractory compositions to be investigated for the critical zone.
3. Improved and positive control by the furnace operator of the rate of feeding by weight of refuse, coke, and limestone to the furnace. Independent and prompt control of the rate of air supply to individual coke air ports, to the refuse air ports as a group, and to the furnace via the refuse chute. Independent control of furnace draft.
4. Increased turbulence in the shaft furnace, above the refuse chute, to hasten combustion of entrained solids.
5. Ample secondary combustion chamber for burnout of solids emitted from furnace. The adequacy of the existing secondary combustion volume was not determined.
6. Reduction in coke consumption by reduction in coke air rate, coupled with preheat of coke air.
7. Improved instrumentation of air flow rates and pressures, feeding rates, furnace radiation, radiation from coke air ports, refractory temperatures, drafts, and solids carryover.
8. The use of limestone to flux the molten glass and ash should be

investigated to establish the conditions under which such use is beneficial or necessary.

9. Commercial use of the slag and metal products should be explored to determine whether they are a source of potential revenue to offset the cost of coke. The effect of slow cooling on the strength of the slag would be of interest if the slag is to be used as an aggregate.
10. The removal of fly ash from the scrubber water, and its disposal, will require attention, especially because of the high loss of mineral matter from the furnace.

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APPENDIX

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APPENDIX A

ANALYSES OF FEED STOCKS AND RESIDUE

Refuse

Refuse was sampled on the charging floor and stored in two closed 55-gallon steel drums, and kept in a cool place. The samples were taken in approximately 10-pound increments during the better periods of furnace operation.

After weighing (265.0 lb) the refuse was spread in a 4-inch layer on the concrete floor of a heated room for preliminary drying, with two turnovers a day. After 5 days the refuse was hand sorted into the components listed below and weighed. The total amounts of some components were transferred directly to metal pans for heat drying. Other lots, such as newspaper and miscellaneous paper, were reduced by hand tearing and quartering for heat drying in pans.

After heat drying at 176 F until constant weights were obtained on two successive days, the components for which dry analyses were not previously known were again hand sorted and the organic matter reduced in a Wiley No. 3 mill for laboratory samples. Small metal, glass, and stone pieces from the garbage and dirt fractions were removed by hand and the weights credited to those components.

The total moisture loss by air and heat drying was 101.9 lb or 38.45 per cent.

Laboratory analyses and Btu determinations were run on 4 samples. The analyses and weights used to establish the composite analysis of the refuse follow. This method is deemed more practical and accurate than attempting to prepare a single composite sample for analysis and Btu determination. Tables A1, A2 and A3 show the steps in arriving at the composite analysis of the as-fired refuse.

TABLE A1. ANALYSES, DRY BASIS, PER CENT

	Cardboard	Newspaper	Misc. Paper	Plastics, leather, rubber	Textiles	Wood
Carbon	45.52	48.36	43.18	79.98	46.19	48.30
Hydrogen	6.08	6.13	5.90	10.75	6.41	5.97
Oxygen	44.53	42.30	44.29	5.25	41.85	42.44
Nitrogen	0.16	0.14	0.18	0.38	2.18	0.29
Sulfur	0.14	0.11	0.09	0.11	0.20	0.11
Inerts	3.57	2.96	6.36	3.53	3.17	2.89
	100.00	100.00	100.00	100.00	100.00	100.00
Btu/lb	7841	8266	7306	16,353	8036	8236
Percent of Dry refuse	4.55	14.06	23.76	3.30	2.53	2.10

	Garbage less bones	Bones	Contents of Oil Filters	Dirt	Glass, Stones, Ceramics,	Metals
Carbon	46.10	41.51	68.32	9.86	0.52	4.54
Hydrogen	6.66	6.59	9.16	1.31	0.07	0.63
Oxygen	24.15	17.17	12.48	2.49	0.36	4.28
Nitrogen	3.08	0.71	0.04	0.52	0.03	0.05
Sulfur	0.15	0.14	0.04	0.10	0.00	0.01
Inerts	19.86	33.88	9.96	85.72	99.02	90.49*
	100.00	100.00	100.00	100.00	100.00	100.00
Btu/lb	8539	8227	14,135	1522	15	68
Percent of Dry refuse	5.77	1.79	1.00	8.96	23.47	8.71

*Metal.

TABLE A2. CONTRIBUTION OF REFUSE COMPONENTS TO TOTAL, IN LB PER 1000 LB DRY REFUSE

	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Metal	Inerts	Btu
Cardboard	20.712	2.766	20.261	0.073	0.064	--	1.624	356,766
Newspaper	67.994	8.619	59.474	0.197	0.155	--	4.161	1,162,200
Misc. paper	102.596	14.018	105.233	0.428	0.214	--	15.111	1,735,906
Pastics, etc.	26.393	3.548	1.732	0.126	0.036	--	1.165	539,649
Textiles	11.686	1.622	10.588	0.551	0.051	--	0.802	203,311
Garbage less bones	26.600	3.843	13.935	1.776	0.087	--	11.459	492,700
Bones	7.430	1.180	3.073	0.127	0.025	--	6.065	147,263
Wood	10.143	1.254	8.912	0.061	0.023	--	0.607	172,956
Filter Contents	6.832	0.916	1.248	0.004	0.004	--	0.996	141,350
Dirt	8.835	1.173	2.231	0.466	0.090	--	76.805	136,371
Glass, etc.	1.220	0.165	0.845	0.070	0.000	--	232.400	3,520
Metal	3.954	0.549	3.728	0.043	0.009	78.817	--	5,923
Totals	294.395	39.653	231.260	3.922	0.758	78.817	351.195	5,097,915

TABLE A3. COMPOSITE ANALYSIS, PER CENT

	Dry	As fired
Moisture	--	38.45
Carbon	29.44	18.12
Hydrogen	3.96	2.44
Oxygen	23.13	14.24
Nitrogen	0.39	0.24
Sulfur	0.08	0.05
Glass, etc.	23.24	14.30
Metal	7.88	4.85
Ash	11.88	7.31
	100.00	100.00
Btu per lb from organics only	5,098	3138

Coke

The high temperature purchased coke was sampled one or two pieces at a time from sacks as charged. The samples were stored in plastic bags inside burlap sacks, and transferred to closed steel drums. One coke sample of two bags was shipped to the Jones and Laughlin Steel Corp. laboratory for chemical analysis. A second sample was taken to New York for moisture determination and size analysis.

The moisture losses of the coke by air and heat drying are tabulated below

Initial weight	84 lb		
Air drying loss		5.625 lb	
Heat drying loss		0.785	
Total moisture loss	6.41	6.410 lb	7.64%
	77.59 lb		

TABLE 4A. TWO COKE ANALYSES BY J&L , PER CENT

	Coke I	Coke II	Avg.	As fired
Moisture	--	--	--	7.64
Carbon	90.87	91.01	90.94	83.99
Hydrogen	0.30	0.33	0.315	0.29
Oxygen	1.04	1.07	1.055	0.97
Nitrogen	0.08	0.01	0.045	0.04
Sulfur	0.58	0.58	0.58	0.54
Ash	7.13	7.00	7.065	6.53
	100.00	100.00	100.00	100.00
Moisture	--	--	--	7.64
Volatile Matter	0.79	0.75	0.77	0.71
Fixed Carbon	92.08	92.25	92.165	85.12
Ash	7.13	7.00	7.065	6.53
	100.00	100.00	100.00	100.00

The heating value was calculated by Dulong formula:

$\text{Btu} = 14{,}544\ C + 62{,}028\ (H - O_2/8) + 4050\ S = 12{,}343$ Btu per lb, as fired.

The bulk density of the coke was determined from an 88 lb sample, which had a volume of 3.01 cu ft.

Bulk density = 88/3.01 = 29.2 lb per cu ft.

An indication of the coke size distribution before charging into the coke elevator is given in the size analysis made on a 34.4 lb lot of the original sample. Circular holes of 4, 3, and 2 inches diameter in a sheet metal plate were used to determine the sizes of individual pieces. All pieces were under 5 inches.

Size, inches	Pieces	Dry weight, lb	Per cent
4 to 5	14	10.875	31.6
3 to 4	19	9.50	27.6
2 to 3	51	13.375	38.9
Under 2	5+dust	0.656	1.9
Total	89+dust	34.406	100.0

During charging there was some breakage and creation of granules that could be heard raining against the dust sampler high in the furnace.

Limestone

Limestone was added to the furnace following additions of coke in amounts of 10 to 15 per cent of the coke. The limestone was of high quality, 2 x 3 inch size, mostly $CaCO_3$, some $MgCO_3$ and less than 5 per cent silica, alumina and iron oxide.

For this purpose the analysis may be assumed as

CaO	56%
CO_2	44%

On heating above 1700 F limestone loses its carbon dioxide, leaving a residue of lime, calcium oxide, which is the flux ingredient desired to lower the viscosity of the high silica coke ash and glass. Lime itself has a melting point of 4676 F, but it dissolves in molten glass and ash.

The bulk density of the limestone used was measured in a 0.787 cu ft container containing 63.25 lb.

Bulk density = 63.25/0.787 = 80.4 lb per cu ft.

APPENDIX B

TEST RUN A, ENTIRE FURNACE

Gas volumes at top of furnace, corrected to 60 F, 30 in. Hg.

	Lb/hr		Cf/lb	Scfh	Volume, % Wet	Volume, % Dry	Weight, % Wet	Weight, % Dry
CO_2	2,381	X	8.548 =	20,353	6.10	6.84	9.46	10.15
CO	24	X	13.506 =	324	0.09	0.10	0.10	0.10
O_2	3,434	X	11.819 =	40,586	12.13	13.60	13.63	14.62
N_2	17,616	X	13.443 =	236,812	70.85	79.46	69.96	75.13
H_2O	1,724	X	21.017 =	36,233	10.83	-	6.85	-
Total	25,179			334,308	100.00	100.00	100.00	100.00

Gas volume at 1270 F at screen. Area of 60 in. dia. = 19.6 sq ft.

$$\frac{334,308}{19.6 \times 60} \times \frac{1270 + 460}{520} = 945 \text{ fpm, } 15.8 \text{ fps.}$$

TEST RUN B, ENTIRE FURNACE

Gas volumes at top of furnace, corrected to 60 F, in Hg.

	Lb/hr		Cf/lb	Scfh	Volume, % Wet	Volume, % Dry	Weight, % Wet	Weight, % Dry
CO_2	2,741	X	8.548 =	23,430	8.48	10.07	13.30	14.79
CO	30	X	13.506 =	405	0.15	0.18	0.15	0.17
O_2	1,982	X	11.819 =	23,425	8.48	10.07	9.62	10.69
N_2	13,780	X	13.443 =	185,245	67.09	79.68	66.86	74.35
H_2O	2,075	X	21.017 =	43,610	15.80	-	10.07	-
Total	20,608			276,115	100.00	100.00	100.00	100.00

Gas volume at 1660 F at screen. Area of 60 in. dia. = 19.6 sq ft.

$$\frac{276,115}{19.6 \times 60} \times \frac{1660 + 460}{520} = 957 \text{ fpm, } 16 \text{ fps}$$

APPENDIX B Continued

TEST RUN A, COKE BED ONLY

Gas volumes leaving top of coke, bed, corrected to 60 F, 30 in. Hg.

						Volume, %		Weight, %	
	Lb/hr		Cf/lb		Scfh	Wet	Dry	Wet	Dry
CO_2	1110.4	X	8.548	=	9,491.7	14.65	14.88	21.31	21.50
CO	116.5	X	13.506	=	1,573.4	2.43	2.47	2.24	2.26
H_2	2.3	X	187.723	=	431.8	0.67	0.68	0.04	0.04
O_2	385.9	X	11.819	=	4,561.0	7.05	7.16	7.41	7.48
N_2	3,547.9	X	13.443	=	47,694.4	73.67	74.81	68.10	68.72
H_2O	47	X	21.017	=	987.8	1.53	-	0.90	-
Total	5,210				64,740.1	100.00	100.00	100.00	100.00

Gas volume at 2620 F at top of coke bed. Area of 40 in. dia. = 8.74 sq ft.

$$\frac{64,740}{8.74 \times 60} \times \frac{2620 + 460}{520} = 731 \text{ fpm, } 12.2 \text{ fps.}$$

TEST RUN B, COKE BED ONLY

Gas volumes leaving top of coke bed, corrected to 60 F, 30 in. Hg.

						Volume, %		Weight, %	
	Lb/hr		Cf/lb		Scfh	Wet	Dry	Wet	Dry
CO_2	1,024.0	X	8.548	=	8,753.2	15.75	15.92	22.93	23.08
CO	187.0	X	13.506	=	2,525.6	4.54	4.59	4.19	4.22
H_2	4.4	X	187.723	=	826.0	1.49	1.51	0.10	0.10
O_2	272.0	X	11.819	=	3,214.8	5.78	5.84	6.09	6.12
N_2	2,950.7	X	13.443	=	39,666.2	71.38	72.14	66.06	66.48
H_2O	28.0	X	21.017	=	588.5	1.06	-	0.63	-
Total	4,466.1				55,574.3	100.00	100.00	100.00	100.00

Gas volume at 2760 F at top of coke bed. Area of 40 in. dia. = 8.74 sq ft.

$$\frac{55,574}{8.74 \times 60} \times \frac{2760 + 460}{520} = 656 \text{ fpm, } 11.0 \text{ fps.}$$

APPENDIX C.

SLAG

The molten product from the bottom of the coke bed consisted of two phases, slag and metal. The slag was a mixture of oxides, mutually miscible, but probably also containing some suspended solids which limited time and temperature did not permit to fully dissolve. Some calcium sulphide probably also existed.

When molten slag flowed freely into the water tank beneath the spout, a black, glassy granulate or frit was produced. When the slag congealed and cooled before entering the water, the granulation was less complete, yielding larger but fragile pieces. The frit was largely a minus 1/4 inch product with low solubility in the tank water. The dissolved solids in the tank water was only 125 parts per million.

The damp frit contained 15.8 per cent moisture immediately after draining. However, with prolonged standing, and especially with stirring or handling, the moisture content dropped to 5.68 per cent.

The true density of the frit without metal was determined equal to 2.74, or 171 lb per cu ft of solid.

The bulk density of the air-dried frit without metal or large slag pieces was found to be 1.374, or 85.7 lb per cu ft. The percentage solids in the dry frit was therefore 100 (85.7)/171 = 50.1 %. The percentage voids was 100 - 50.1 = 49.9 %.

A sample of wet frit with metal inclusions was taken as it was discharged from the frit conveyor and allowed to drain. The drained residue weighed 248.5 lb and had a volume of 2.59 cu ft. The resultant bulk density was 248.5/2.59 = 96.0 lb per cu ft or 1.51.

Slag Analyses

The J&L personnel took 41 slag samples during 5 days of the tests and produced the analyses summarized below.

Ten slag samples were ground and spectrographically analyzed semi-quantitatively. Another 12 samples were first separated magnetically after which the magnetic and non-magnetic fractions were analyzed separately spectrographically. The ranges of results are summarized in Table C1.

Table C1. Analyses of Slag Samples

	Non-Magnetic	Magnetic	As Rec'd.	Hd. Pkd.*	Probable non-magn. Avg.
Silicon	> 10	> 10	> 10	> 10	> 10
Titanium	0.3-0.5	0.3-0.5	1	0.3-0.5	0.4
Aluminum	5-7	3-5	3-5	0.3-0.7	4
Iron	3-5	3-5	1-8	> 10	4
Chromium	0.01-0.3	0-0.3	0.01-0.03	0.01-0.03	0.02
Magnesium	1-3	1-3	1	0.5 -3	2
Copper	0.1 -0.3	0.03-0.3	0.01-0.08	0.01-0.05	0.2
Zinc	0.1 - 0.3	-	-	-	0.2
Manganese	0.1 -0.3	0.3 -0.5	0.1 -0.3	0.5 -0.8	0.2
Calcium	3-5	3 -5	5 -8	3 -5	5
Sodium	3-5	1 -3	1	3 -5	2.5
Tin	0-0.05		< 0.01	0.01-0.03	0.02

* Magnetic droplets were handpicked from the slag sample after one pass through the jaw crusher.

From the above JPL data, analyses of fly ash by WCMT, and published data (11), it was possible to prepare Tables C2 and C3. Table C3 gives the approximated percentages and Table C2 reports the corresponding weight balance for the slag and fly ash for Test Run B. Reasonable approximations had to be made for completeness.

Table C2. Oxide Weights for Run B, Pounds per Hour

	From Refuse	+	From Metal	+	From Coke	+	From Lime	=	Total	-	To Fly Ash	=	To Slag
P_2O_5	4.58		-		-		-		4.58		0.24		4.34
SiO_2	430.85		-		14.16		1.23		446.24		80.83		365.41
TiO_2	8.85		0.16		0.52		-		9.53		5.60		3.93
Al_2O_3	64.65		8.78		6.06		0.41		79.90		35.50		44.40
MgO	26.66		0.50		0.26		2.05		29.47		10.00		19.47
ZnO	2.24		0.62		-		-		2.86		1.40		1.46
CuO	1.50		0.36		-		-		1.86		0.40		1.46
FeO	38.14		13.98		2.08		-		54.20		24.00		30.20
MnO	1.86		-		-		-		1.86		0.40		1.46
CaO	73.57		-		0.52		37.31		111.40		28.00		83.40
BaO	0.07		-		-		-		0.07		0.01		0.06
Na_2O	25.51		-		0.26		-		25.77		6.00		19.77
K_2O	6.09		-		0.13		-		6.22		4.00		2.22
SO_3	3.75		-		4.12		-		7.87		2.62		5.25
Other*	3.68		0.1		0.39		-		4.17		1.00		3.17
	692.00	+	24.5	+	28.50	+	41.00	=	786.00	-	200.00	=	586.00

*Other = Chlorine and oxides of tin, chromium, zirconium, boron, lead cobalt, vanadium, molybdenum, and nickel.

Table C5. Oxides in Descending Order of Increasing Basic Strength

Sources and Contribution to Fly Ash and Slag, per cent. Based on Test B.

↑ More acid

More basic ↓

Oxides	From Refuse	From Metal	From Coke	From Lime	Total	To Fly Ash	To Slag
Lb/hr	692	24.5	28.5	41	786	200	586
P_2O_5	0.67	-	-	-	0.58	0.12	0.74
SiO_2	62.26	-	49.68	3	56.78	40.41	62.37
TiO_2	1.28	0.65	1.83	-	1.21	2.80	0.67
Al_2O_3	9.34	35.84	21.26	1	10.17	17.75	7.58
MgO	3.86	2.04	0.91	5	3.75	5.00	3.32
CuO	0.22	1.47	-	-	0.24	0.20	0.25
ZnO	0.32	2.53	-	-	0.36	0.70	0.25
FeO	5.50	57.06	7.30	-	6.90	12.00	5.17
MnO	0.27	-	-	-	0.24	0.20	0.25
CaO	10.63	-	1.83	91	14.17	14.00	14.22
BaO	0.01	-	-	-	0.01	0.01	0.01
Na_2O	3.69	-	0.91	-	3.27	3.00	3.37
K_2O	0.88	-	0.46	-	0.79	2.00	0.38
SO_3	0.54	-	14.45	-	1.00	1.31	0.90
Other	0.53	0.41	1.37	-	0.55	0.50	0.54
Total, %	100.00	100.00	100.00	100	100.00	100.00	100.00

To achieve a base/acid ratio of 0.9 for low viscosity slag, more limestone would be charged. Table C4 indicates that 272 lb of calcined limestone is needed to supplement the initial 41 lb. As 44 per cent of limestone is CO_2, (41 + 272)/(1-0.44) = 560 lb limestone per hr is required, or 350 lb per ton of refuse.

Table C4. Run B Slag with Additional Lime for Low Viscosity

	Run B Slag, lb		Added CaO, lb		Projected Slag, lb	Wgt. %
P_2O_5	4.34			=	4.34	0.51
SiO_2	365.41	+	8.16	=	373.57	43.50
TiO_2	3.93			=	3.93	0.46
Al_2O_3	44.40	+	2.72	=	47.12	5.5
MgO	19.47	+	13.60	=	33.07	3.85
ZnO	1.46			=	1.46	0.17
CuO	1.46			=	1.46	0.17
FeO	30.20			=	30.20	3.52
MnO	1.46			=	1.46	0.17
CaO	83.40	+	247.52	=	330.92	38.60
BaO	0.06			=	0.06	0.01
Na_2O	19.77			=	19.77	2.30
K_2O	2.22			=	2.22	0.26
SO_3	5.25			=	5.25	0.61
Other*	3.17			=	3.17	0.37
	586.00	+	272.00	=	858.00	100.00

$$\frac{\text{Base}}{\text{Acid}} = \frac{385.98}{428.96} = 0.90$$

As the indicated limestone addition would undoubtedly be impractical in most places, a compromise is necessary. Preheating the coke air would increase the slag temperature to offset the need for much if any limestone.

D. Metal Inclusions in Slag

The metal pellets that resulted from the water quenching of the molten residue were spherical when under 1/4 inch diameter or flattened rounded if larger up to about 1 inch. Larger pieces of irregular shape were rare and probably resulted when the slag flowed slowly.

The pellets were usually free of slag and iron bright when first removed from the water, but became rusty with exposure to the air. The pellets were too hard to file; 61 Rockwell C hardness was measured on several pellets. When broken by hammer, the fracture was that of white cast iron. The pellets contained gas bubbles.

A 71 lb sample of moist frit and metal inclusions was air dried and magnetically separated, with the following results:

		Wet basis, %	Dry basis, %
Dry slag	51.75 lb	72.89	77.3
Dry metal	15.22	21.43	22.7
Moisture loss	4.03	5.68	-
Initial wgt.	71.00 lb	100.00	100.0

The proportions of slag and metal will vary with the refuse, but the above data are indicative.

The metal pellets alone had a bulk density of 3.62, or 226 lb per cu ft. The voids were 46.5 per cent.

Determined by water displacement of a 15 lb sample, the true density of the metal pellets was found to be 6.77. The metal contained bubbles, the volume of which can be approximated by assuming the density of white cast iron at 475 lb per cu ft, or 7.61. Thus the bubble volume = 11 per cent of the solid metal.

Nineteen (19) samples of the magnetically separated metallic droplets were semi-quantitatively analyzed spectrographically by the J&L Laboratory. The results were remarkably uniform. The ranges are summarized below.

Table D1. Elements in Metallic Fraction of Residue, per cent

Iron	Over 10	Chromium	0.1 -0.5
Silicon	1 -5	Molybdenum	0.01-0.03
Manganese	0.1 -0.3	Tin	0.00-0.03
Titanium	0.01-0.3	Copper	0.1 -0.8
Aluminum	0.01-0.05	Magnesium	0.01
Nickel	0.1 -0.5	Silver	< 0.01

Carbon and sulfur were not reported, but the carbon content can be assumed at about 2 per cent, and sulfur under 0.1 per cent.

APPENDIX E

ECONOMIC EVALUATION

Assuming the satisfactory solution of the technical factors, the economics of the Melt-Zit system may be compared with those of conventional municipal incinerators. Opinions expressed are those of the writer.

A Melt-Zit incinerator plant would probably require the same land area, roadways, building, refuse handling, secondary combustion chamber, gas tempering chamber, dust collector, induced-draft fan and chimney. Facilities for receiving, storing and conveying coke and limestone would be additional. It may be advisable to enclose the storage area and conveyors for coke and limestone.

The Melt-Zit furnace is, in effect, the primary combustion chamber or furnace of the incinerator plant. The maximum size is currently estimated at 15 tons an hr or 360 tons a day, equal to a conventional rectangular furnace of 500 sq ft of grate area (12 x 45 ft inside furnace plan area). Because of its tall circular construction and equal volumetric combustion rate, the Melt-Zit furnace will probably have a refractory wall area and cost comparable to conventional furnaces. The cost of a stoker and hydraulic drive would be saved.

A tank or sluice trough for granulating the frit could be a simplification over the normal quenching and transport of incinerator residue.

The frit conveyor could be small as there is no need to oversize for the handling of large objects. A continuous casting machine for the production of larger pieces of slag and metal would entail additional expense, that would have to be offset by market values for the products. Water consumption of the Melt-Zit plant would be far less than for conventional incinerators.

The investment cost of municipal incinerator plants is currently in the range of $7500 to $10,000 per ton day of capacity, based on 24-hr operation. For a comparable plant on the same site and with the same architectural treatment, it is not evident as yet how the Melt-Zit system could cost less than 90 to 100 per cent that of a conventional incinerator of good quality.

In consideration of operating expenses, savings in operating personnel with Melt-Zit furnaces are not foreseen. A single operator now manages each present incinerator furnace; and at least one would be required for each Melt-Zit furnace, even with mechanical aids for rodding air ports and full control of air and feed at a single console. The receiving, storing and conveying of coke and limestone would require additional manpower. Supplementary personnel is needed in both types of plants for maintenance, housekeeping, etc.

The Melt-Zit system incurs costs of coke and limestone which are not common to other incinerators. These added costs must be offset by additional benefits, such as reduced cost of residue disposal or of sales of the denser, combustible-free residue. The slag and the larger metal pellets may also be saleable. These benefits will very with locations.

High temperature coke of a screen size suitable for the Melt-Zit process costs $28 to $34 a net ton delivered in the New Jersey-to-Massachusetts area. Limestone costs $7.50 a ton delivered in the same area. The cost of these raw materials would have to be determined for specific locations. For the following examples, coke has been assumed at $32 a ton, and limestone at $7.50 a ton.

Under Test B conditions the coke and limestone would cost $4.17 per ton of refuse, which would be excessively high. If the coke requirement could be reduced to 1 ton per 20 tons of refuse, the coke cost would be $1.60 a ton of refuse. For each 100 lb of limestone added per ton of refuse the cost would increase by $0.375. Further development of the process is necessary to establish an economical consumption of coke and limestone.

Because of its more compact nature and the absence of putrescible matter, Melt-Zit residue could be deposited in landfill without daily cover of soil. The magnitude of this saving would have to be determined in individual cases, both as regards saving of land volume and cost of operating a landfill site.

The magnetic separation of the metal pellets from the slag granulate could readily be done in practice, and some revenue might be realized from the sale of the metal. It remains to be proved that the metal has a commercial value either as melting stock or because of its physical properties in its present form.

The slag and frit produced on the test were friable and readily crushed under foot. Their strength was not comparable to sand and stone as used in concrete or road building. The production of a stronger aggregate by slow cooling of the slag is a possibility, as is the production of a blown or foamed product. These possibilities have not been proved technically, and their economic benefits would be accompanied by additional costs.

Compared with conventional incinerators the Melt-Zit process could be very economical in water usage. The residue quench water absorbs about 300,000 Btu per ton of refuse charged to the furnace. If the heat of the residue is converted to vapor by allowing the water to boil, the water consumption would be only 300 to 400 lb (36 to 48 gal) of water per ton of refuse. If boiling is to be prevented and the water is to be cooled by an evaporation tower outside the plant, the water consumption would be only slightly more.

Water use by a flue gas scrubber or by a spray chamber for gas tempering would be 15 to 25 per cent more than that of other plants of the same tonnage input, because of the additional heat from the coke. However, the run-off water from the scrubber and/or spray chamber could be used for slag quenching. The result would be little or no discharge of process water to sewers or streams. The water evaporated in a scrubber would be approximately 800 gallons per ton of refuse. The total water consumption for process would thus be only about 850 gallons per ton, as compared with 2000 gallons per ton for some conventional incinerators. The water saving for the Melt-Zit unit would be 1150 gal per refuse ton. Water costs are highly variable. At 30 cents per 1000 gallons, the saving would be $0.345 per refuse ton.

The inherent difference in power consumption between conventional incinerators and Melt-Zit plants was not apparent from the tests. The power requirements would have to be evaluated from full-scale designs.